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Schneve

# ELECTRICAL INSTRUMENTS AND TESTING

## How to Use the Voltmeter, Ammeter, Galvanometer, Potentiometer, Ohmmeter, and the Wheatstone Bridge

BY

NORMAN H. SCHNEIDER

*Author of "The Care and Management of Electric Plants," "Induction Coils," "Circuits and Diagrams," &c, &c.*

**Practically explained with numerous examples worked out and fully Illustrated with Diagrams and Drawings**

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# INTRODUCTION.

**Classification.** Electrical instruments used in the detection or measurement of electrical currents are divisible into two classes.

The first class includes such as show the presence of a current without directly indicating its value in units of measurement.

To this class belong the various kinds of galvanometers.

Instruments of the second class indicate by the movement of pointers over dials or some such means the value of the electrical current passing.

The dial under the pointer or index is graduated into divisions representing units of measurement. Examples of this class are the voltmeter, ammeter and wattmeter.

Instruments which leave a record of the fluctuations or the current strength for a given period of time are Recording Voltmeters, Recording Watt-

meters, etc., according to the unit by which their records are read.

As the underlying principles of instruments belonging to the latter class are mostly to be found in those of the first class, the latter will be first considered.

# CHAPTER I.

## GALVANOMETERS.

**The Simple Galvanometer.** Perhaps the simplest form of galvanometer is shown in Fig. 1, and although home made, is capable of many uses.

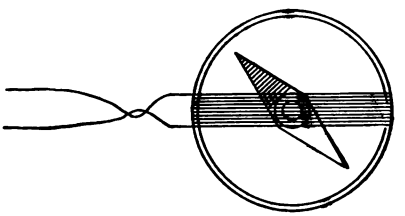

FIG. 1.

An ordinary mariner's compass has a few turns of fine insulated copper wire wound around its case, a suitable gauge being No. 26 B. & S. or No. 28 S.W.G.

If current from a battery or other source be sent through the coil of wire, the magnetic needle will tend to turn at an angle to the wire turns, providing the galvanometer has first been set so that both needle and wire turns are parallel.

The stronger the current through the coil, the farther the needle swings out from it.

And reversing the connections will cause the needle to swing in a reversed direction as the current is reversed in its flow around the coil.

But it will be noticed that the amount of the needle swing is not in proportion to the strength of the current.

Let the circle or card forming the bottom of the compass case be divided into 360 degrees having the zero where one end of the needle normally rests.

On connecting the coil ends to a dry cell suppose the needle swings out to 30 degrees.

If a second cell is put in series with the first and the two cells connected to the coil as before the swing may now only be 35 degrees, a gain of but five degrees by doubling the current strength instead of a gain of 30 degrees.

It is to be remarked before proceeding that these readings as they are termed are only for sake of example, not being necessarily exactly the number of degrees obtained in any experiment.

If a galvanometer gives a large reading with one cell as compared with a reading taken under precisely similar conditions on another galvanometer the one giving the largest reading will be said to have the greater sensibility.

The movement of a galvanometer needle from one position to another is termed its deflection and is measured in degrees.

Now the primary laws of electricity teach that the current strength or rate of flow depend upon the electromotive force (e.m.f.) or voltage impelling that current and upon the resistance of the circuit through which it travels.

Increasing the e.m.f. or decreasing the resistance increases the current flow, and vice versa, decreasing the e.m.f. or increasing the resistance decreases the current flow.*

In order to decrease the deflection of the needle resistance must be added to the circuit, this may be done by means of a rheostat.

One form of rheostat would consist of coils of wire so connected that one or any desired number of coils could be inserted in series with the galvanometer. The electrical energy expended in these coils being therefore not available in the galvanometer coils would have no effect upon its needle deflection which would be thereby reduced.

The sensibility of this galvanometer will depend upon the ampere turns of its coil (neglecting friction, etc.), and the coil winding should be suitable for the current in the circuit in which it is used.

If the galvanometer is to measure currents in a circuit of low resistance, its coil should be also of low resistance and vice versa.

The meaning of ampere turns must be thoroughly understood. It will suffice here to remark that one ampere traveling round the needle for

*See "Electricity and Its Laws, for Beginners," for the elementary laws governing electric current.

one turn would equal one hundredth of an ampere for one hundred turns and the needle deflection would be the same in each case.

In a circuit of low resistance, a large current would flow (presumably) and this current would not need to travel around the needle as many times as the lesser current in a circuit of higher resistance to produce the same deflection. In this case using a coil of many fine wire turns in the low resistance circuit would only reduce the current around the needle. And using a coil of large wire and few turns would not give ampere turns enough in a circuit of high resistance.

An apparent contradiction may be met by the experimenter who in adding more turns of wire to a simple galvanometer gets a greater deflection of the needle. This, however, only shows that the ampere turns were not sufficient in the first case, and therefore the contradiction does not exist.

To sum up, the reason for using a large number of fine wire turns as is done in some galvanometers is that the current strength is often so small as to require its circulation many times around the needle to produce the requisite ampere turns.

It is very common practice to speak of a coil as being wound to a given resistance when ampere turns are really desired. If resistance were the object, a resistance metal could be used to advantage.

The relation of resistance and diameter of copper wire is given in Table I., from which may be

# TABLE I.

## Table Showing Gauge Diameter, Area and Resistance of Copper Wire.

| Gauge No. | Brown and Sharpe Gauge. | | | Standard Wire Gauge. | | |
|---|---|---|---|---|---|---|
| | Diameter inches. | Circular Mils. | Ohms per 1000 ft. at 15° Cent. | Diameter inches. | Circular Mils. | Ohms per 1000 ft. at 15° Cent. |
| 0000 | .4600 | 211600 | .048 | .400 | 160000 | .063 |
| 000 | .4096 | 167810 | .060 | .372 | 138384 | .073 |
| 00 | .3648 | 133080 | .076 | .348 | 121104 | .084 |
| 0 | .3249 | 105590 | .096 | .324 | 104976 | .096 |
| 1 | .2893 | 83694 | .121 | .300 | 90000 | .113 |
| 2 | .2576 | 66373 | .153 | .276 | 76176 | .133 |
| 3 | .2294 | 52633 | .193 | .252 | 63504 | .160 |
| 4 | .2043 | 41743 | .243 | .232 | 53824 | .189 |
| 5 | .1819 | 33102 | .307 | .212 | 44944 | .226 |
| 6 | .1620 | 26250 | .387 | .192 | 36864 | .276 |
| 7 | .1442 | 20817 | .489 | .176 | 30976 | .329 |
| 8 | .1284 | 16510 | .616 | .160 | 25600 | .397 |
| 9 | .1144 | 13094 | .777 | .144 | 20736 | .490 |
| 10 | .1018 | 10382 | .980 | .128 | 16384 | .624 |
| 11 | .0907 | 8233.7 | 1.236 | .116 | 13456 | .758 |
| 12 | .0808 | 6530.3 | 1.559 | .104 | 10816 | .940 |
| 13 | .0719 | 5178.2 | 1.966 | .092 | 8464 | 1.202 |
| 14 | .0640 | 4106.2 | 2.479 | .080 | 6400 | 1.590 |
| 15 | .0570 | 3255.8 | 3.127 | .072 | 5184 | 1.963 |
| 16 | .0508 | 2582.7 | 3.942 | .064 | 4096 | 2.485 |
| 17 | .0452 | 2047.6 | 4.972 | .056 | 3136 | 3.246 |
| 18 | .0403 | 1624.9 | 6.269 | .048 | 2304 | 4.420 |
| 20 | .0319 | 1022 | 10.140 | .036 | 1296 | 8.038 |
| 22 | .0253 | 642 | 16.120 | .028 | 784 | 13.212 |
| 24 | .0201 | 404 | 25.630 | .022 | 484 | 21.394 |
| 26 | .0159 | 251 | 40.750 | .018 | 324 | 31.963 |
| 28 | .0126 | 160 | 67.790 | .015 | 219 | 47.707 |
| 30 | .0100 | 100 | 103.300 | .012 | 154 | 66.866 |
| 32 | .0080 | 63 | 183. | .011 | 106 | 103.410 |
| 34 | .0063 | 40 | 291. | .009 | 84 | 127.860 |
| 36 | .0050 | 25. | 462. | .008 | 57 | 189.660 |

computed the size of wire to use for a galvanometer coil.

**Deflections not Uniform.** The needle does not move twice as far for twice the current because as soon as it starts to move it commences to get out of the strongest influence of the coil, or out of the intense part of the field.

If the coil is very large and the needle very small, then the latter can deflect more uniformly as the field is more uniform.

**Tangent Galvanometer.** The tangent galvanometer has a coil wound around a ring perhaps twelve inches in diameter, and the needle is a fraction of an inch in length.

In this case the deflections of the needle are compared by referring to a table of tangents, Table II.

A tangent is a straight line perpendicular to the diameter of a circle, limited in length by the sides of the angle one of which is the diameter of the circle.

In Fig. 2 the dotted line is the diameter of the circle and passes clear through the zero mark. *N* is a straight line drawn through the centre of the pointer or needle, in other words shows the number of degrees of deflection. The degrees between this line and the zero will be the number of degrees forming the angle of deflection, angles being measured in degrees. If the pointer were at

45° the angle would be one of 45° or half a right angle (90°).

*T* is a straight line perpendicular to the diame ter but cut by *N*. The portion between the diame· ter line and where it is cut by *N* is the tangent. Fig. 2 represents an angle of about 15°, that is, the needle is deflected 15°. Fig. 3 shows the tangent of an angle of about 30°, Fig. 4 the tangent of 60° and Fig. 5 the tangent of about 75°.

It will be seen that the tangent increases in

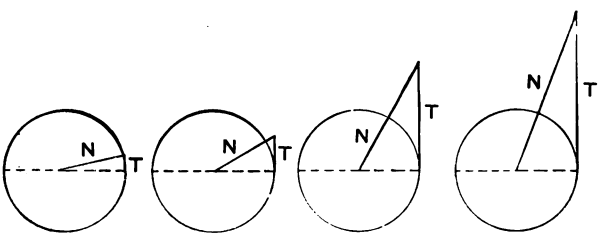


FIG. 2. FIG. 3. FIG. 4. FIG. 5

length very rapidly, far more so than the deflection angle.

To make a comparison, let the needle be deflected 5°, its tangent will be .0875, double the deflection, the tangent of 10° is .1763, more than double the one of 5°.

Deflect the needle to 30° or six times its first deflection and the tangent is .5774, about seven times.

A still farther deflection to 60°, or twelve times

the first one, the tangent is now 1.7321, or about twenty times that of 5°.

In a tangent galvanometer when it is desired to compare the strength of two currents, readings

TABLE II.

Natural Tangents of Angles.

| Angle Degrees | Tangent | Angle Degrees | Tangent | Angle Degrees | Tangent |
|---|---|---|---|---|---|
| 1 | .0174 | 31 | .6008 | 61 | 1.8040 |
| 2 | .0349 | 32 | .6248 | 62 | 1.8807 |
| 3 | .0524 | 33 | .6494 | 63 | 1.9626 |
| 4 | .0699 | 34 | .6745 | 64 | 2.0503 |
| 5 | .0874 | 35 | .7002 | 65 | 2.1445 |
| 6 | .1051 | 36 | .7265 | 66 | 2.2460 |
| 7 | .1227 | 37 | .7535 | 67 | 2.3559 |
| 8 | .1405 | 38 | .7812 | 68 | 2.4751 |
| 9 | .1583 | 39 | .8097 | 69 | 2.6051 |
| 10 | .1768 | 40 | .8391 | 70 | 2.7475 |
| 11 | .1943 | 41 | .8692 | 71 | 2.9042 |
| 12 | .2125 | 42 | .9004 | 72 | 3.0777 |
| 13 | .2308 | 43 | .9325 | 73 | 3.2709 |
| 14 | .2493 | 44 | .9656 | 74 | 3.4879 |
| 15 | .2679 | 45 | 1.0000 | 75 | 3.7321 |
| 16 | .2867 | 46 | 1.0355 | 76 | 4.0108 |
| 17 | .3057 | 47 | 1.0724 | 77 | 4.3315 |
| 18 | .3249 | 48 | 1.1106 | 78 | 4.7046 |
| 19 | .3443 | 49 | 1.1504 | 79 | 5.1446 |
| 20 | .3639 | 50 | 1.1918 | 80 | 5.6713 |
| 21 | .3838 | 51 | 1.2349 | 81 | 6.3138 |
| 22 | .4040 | 52 | 1.2799 | 82 | 7.1154 |
| 23 | .4244 | 53 | 1.3270 | 83 | 8.1443 |
| 24 | .4452 | 54 | 1.3764 | 84 | 9.5144 |
| 25 | .4663 | 55 | 1.4281 | 85 | 11.4301 |
| 26 | .4887 | 56 | 1.4826 | 86 | 14.3007 |
| 27 | .5095 | 57 | 1.5399 | 87 | 19.0811 |
| 28 | .5317 | 58 | 1.6003 | 88 | 28.6863 |
| 29 | .5543 | 59 | 1.6643 | 89 | 57.2900 |
| 30 | .5773 | 60 | 1.7321 | 90 | infinite |

are made of the two deflections obtained. The tangents of these angles or deflections are then compared.

If one deflection were 11° and the second one

63°, the second current would be nearly ten times the greater, or as .1944 is to 1.9626.

**Influence of the Earth's Magnetic Field.** It was necessary to move the galvanometer around so as to bring the needle point to zero.

As the galvanometer was made out of a compass this was done because the needle tended to point to the magnetic *N* and *S* of the earth.

In order to avoid having to turn the instrument about before using it, the influence of the earth's

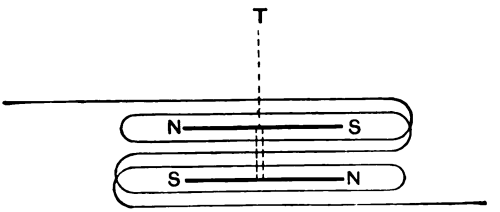


FIG. 6.

magnetic field is compensated for in the astatic galvanometer.

**The Astatic Galvanometer.** In Fig. 6 two magnetic needles are rigidly attached to a stem in such manner that the *N* pole of one is over the *S* pole of the other. If both needles are equally strong, such a combination on being suspended by a fine thread *T* or balanced on a point, would stay in whatever direction it was placed. It would be entirely unaffected by the earth's mag-

netic field, one needle neutralizing the other. But this is not obtained in practice, the pair of needles take a set position in which, however, their movement is little restrained by the earth's magnetism.

The coil is wound as shown in order that the

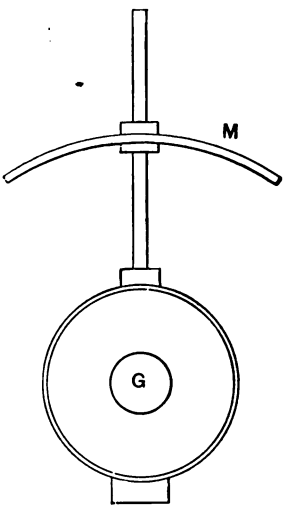


FIG. 7.

current may tend to turn each needle in the same direction.

**Compensating Magnet.** A compensating magnet is used with certain forms of galvanometers to neutralize the effect of the earth's magnetism on the needle.

It is generally of a curved form as in Fig. 7 at *M*, being mounted on a rod upon which it can be slid up or down over the galvanometer *G*. It can also be rotated on its axis.

An ordinary bar magnet is used for the same purpose by placing it in different positions with relation to the galvanometer until the desired result is obtained.

Where the latter method is pursued it is a good plan to attach the magnet to a block of lead so that a slight jar will not displace it.

# CHAPTER II.

## GALVANOMETERS.

In describing galvanometers, the terms constant, figure of merit and sensibility are used.

A full description of these terms rightly belongs to the pages on practical testing.

But it may be stated here, that these terms are those by which galvanometers are compared when considering their sensitiveness.

The constant or sensibility is the number of ohms resistance through which an e.m.f. of one volt will cause the galvanometer to give a deflection of one degree on a standard scale.

A more complete explanation of the terms will be found in a later chapter.

**The Thompson Reflecting Galvanometer.** In the Thompson reflecting galvanometer, a flat mirror of less than one-half inch in diameter has a number of fine steel magnets fastened on its back. This mirror-magnet combination is suspended by a fibre of cocoon silk inside a coil of many turns of fine insulated wire.

When the magnets are deflected by current flowing in the coil, the mirror also turns, and a beam of light directed on it is reflected on a curved scale.

FIG. 8.

This scale has the zero mark in the centre, readings being thus possible in either direction.

A compensating magnet is attached on a rod fixed to the top of the case and leveling screws are provided to level the instrument.

As the mirror is small and light it has little momentum, its moving in a small chamber gives it an air cushion, and it quickly comes to rest or is "dead beat."

In Fig. 8 is the tripod form of Thompson reflecting galvanometer.

This instrument is made with interchangeable coils from 150 ohms to 5000 ohms in resistance. The sensibility for minute currents with the 5000 ohm coil is very great.

A four coil reflecting galvanometer of the Thompson pattern in Fig. 9 has a hinged door which opens, breaking the circuit through the coils.

This gives easy access to the suspension system. Spring contacts *C* seen at the lower part of the base make connection at *P* when the door is shut.

The magnetic system is suspended from a tube *B* equipped with an adjusting screw *K*.

A compensating or control magnet *M* is fitted in a tube and adjusted by the milled head *S*.

**Moving Coil Galvanometers.** One of the greatest drawbacks to the use of galvanometers built on the Thompson pattern is their sensitiveness to external influences. In large cities where trolley cars and buildings of iron frame construction abound, this type of instrument needs constant adjustment. Allowances and checks have to

enter into tests made with them so largely as to almost prohibit their use.

A class of galvanometers based upon the rotation of a coil carrying current in a magnetic field

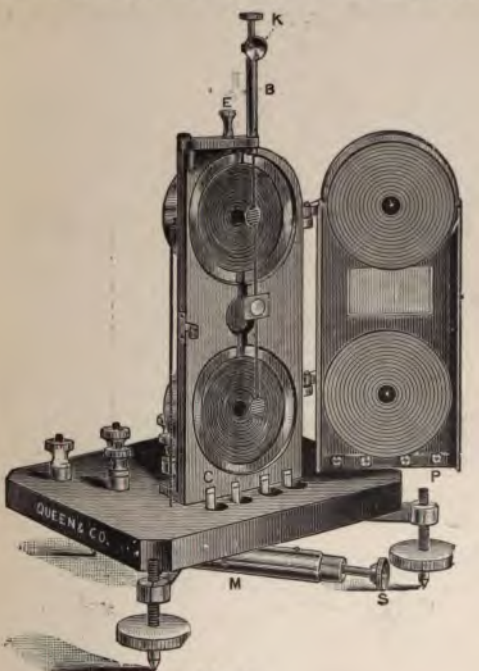


FIG. 9.

has been so perfected that they are being almost universally adopted.

The pioneer moving coil galvanometer is that invented by D'Arsonval.

**The D'Arsonval Galvanometer.** In Fig. 10 *H* is a horseshoe shaped magnet or series of magnets bolted together and to the base *B* which is supplied with leveling screws *LL*.

A core of soft iron *I* is held stationary, around

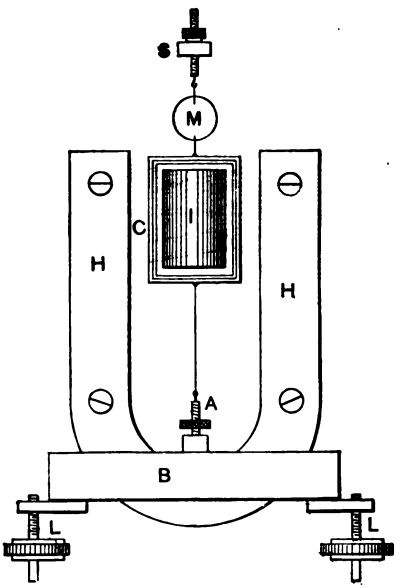


FIG. 10.

which turns a coil of fine insulated wire *C*. This coil is suspended between adjustable screws *SA* by fine wires in such manner that current entering at the screw *S* passes through the coil and out at *A*, or vice versa.

A tiny mirror *M* of circular form is also carried by the suspension wires and turns with the coil.

When current is applied to *S* and *A*, the coil tends to turn in the magnetic field formed by the magnet poles and strengthened by the soft iron core *I*.

The instrument is so constructed that the magnetic field is as nearly uniform as possible, and the deflections of *M* are proportional to the current flowing through *C*.

**Horizontal Magnet.** This type of D'Arsonval galvanometer is shown in elevation in Fig. 11.

In this galvanometer the coil and mirror are suspended in a tube by a phosphor bronze strip.

This form of construction permits the mirror and coil to swing but to return to zero without any distortion from twisting of the suspension or "set."

Interchangeable tubes are furnished with coils of varying resistances and sensibilities. The 20 ohm tube has a sensibility of 75 megohms (75 million ohms). The 4000 ohm tube has the extreme sensibility of 1750 megohms.

The deflections in these instruments are proportional to the current.

The moving system is either dead beat or ballistic.

The ballistic type is adapted for the measurement of currents of short duration. The current has ceased before the deflection is complete. But

the impetus received by the coil carries it to a distance and gives the possibility of measuring the current strength from the distance of swing.

A form of D'Arsonval galvanometer, Fig. 12, is adapted for attachment to a wall. The galvano-

FIG. 11.

meter is entirely enclosed in a cylindrical case, the mirror deflections being observed through a window in front.

A removable bracket carries a reading telescope and scale so proportioned that it gives the same

effect as a standard millimeter scale at a distance of one meter.

Gimbal suspension of the galvanometer itself causes it to be self-leveling.

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FIG. 12.

The scale deflections are directly proportional to the current causing them.

The sensibility is about 500 megohms per volt of battery used, a sensibility sufficient for all ordinary measurements.

In the Willyoung form of D'Arsonval galvanometer the suspension of the coil is shown in Fig. 13.

*S* is the coil; *U* and *L* the suspensions, the latter being in the form of a spiral spring. *T* is a torsion head for adjustment of the coil to zero reading.

FIG. 13.

To clamp the coil for purposes of traveling, the head *C* is turned, *E* then raises the coil taking its weight from *u* and clamps it against *D*.

The upper spindle *A* admits of the adjustment

of new suspension wires. It is clamped by a set screw at *e*.

The upper suspension is grounded on the tube case, the lower one *L* is connected to a platinum faced disc *F*.

The electrical connections are therefore from one binding post through the case, down *u*, coil *L*

FIG. 14.

and out through *F* to a spring connected to a binding post.

A portable D'Arsonval galvanometer, Fig. 14, is constructed with a sensibility of upwards of one megohm. It is dead beat and has a scale divided from a central zero into 50 divisions right or left.

As has been remarked before, instruments constructed on the D'Arsonval principle read in direct proportion to the current passing.

And they are not affected by external magnetic fields. An instrument similar to the above with 100 cells of battery would be capable of measuring insulations up to 100 megohms, and higher if fractions of a deflection be read.

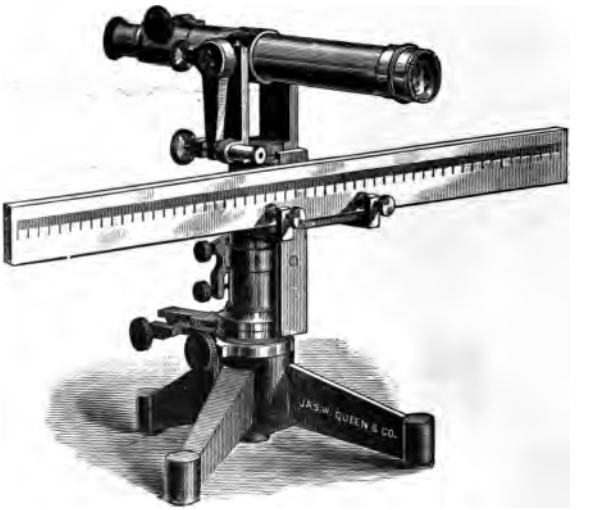



FIG. 15.

**Scale and Lamp.** The oscillations of the galvanometer mirror are read in two ways. By watching a spot of light on a scale or observing the image of the scale reflected in the mirror by means of a telescope.

The scale is made in various forms but in principle resembles that in Fig. 15

# CHAPTER III.

## Rheostats, Keys and Shunts.

**Rheostats.** The resistances used in testing-rheostats are mostly made of insulated wire having a high specific resistance, and but little liable to change under varying temperature conditions.

They are also wound non-inductively so that no currents due to inductance shall affect the galvanometer. This end is obtained by winding the wire so that the current shall flow half around the spool in one direction and half around it in the reverse direction.

The piece of wire may be either doubled upon itself and then wound on, or may be wound on in two equal lengths, the inside ends being soldered together. The outside ends are for attachment to the circuit.

It is always desirable that the binding posts or terminals of a resistance coil be made large enough that they do not offer any perceptible resistance to the circuit.

In the practical construction of rheostats for testing, they are adjustable in several ways. The

cutting in or out of coils is effected by plugs or sliding switches.

In the plug form of switch, Fig. 16, a brass taper plug *P* is inserted in a hole between brass strips *S*, connecting these strips together.

The resistance coils *R* are connected as shown. If one plug be now removed from the hole, a coil becomes part of the circuit between *A B*. A second plug cuts in another coil and so on. Each coil thus cut in adds its resistance to the circuit.

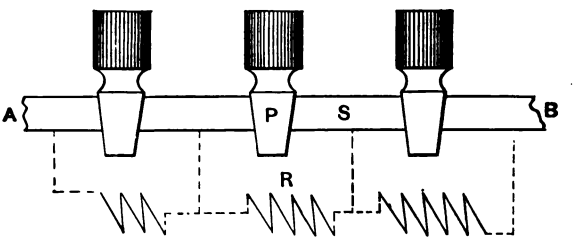



FIG. 16.

The chief disadvantages of this system are that it requires a plug for each coil, and that if a plug be not tight a coil is not entirely cut out.

Plug switches are also arranged to connect *in* coils when inserted in holes.

Modern rheostats are being constructed, however, with sliding switches which cannot get lost and which make good firm contact.

**Resistance Wires.** The choice of a metal for resistances to be used for testing purposes must be

determined by several points. The metal must change in resistance as little as possible under varying temperatures.

It is also desirable that the metal used shall have a high specific resistance, that is, its resistance per unit of length shall be as great as possible in comparison with other metals. This is in order to keep the coil as small as possible, resistance coils with figures as high as 100,000 ohms being in common use.

German silver, although formerly much used, has been replaced by several compound metals.

The composition of some commonly used resistance wires is as follows: German silver, copper 60 parts, zinc 26 parts, nickel 14 parts. This alloy is also made with 30 per cent. nickel.

Platinum silver contains platinum 67 parts, silver 33 parts.

Platinoid is German silver 98 parts, tungsten 2 parts.

Manganin contains copper 84 parts, manganese 4 parts, nickel 12 parts.

The relative resistances of the above are in comparison with copper as 1, as follows: German silver 12, platinum silver 15, platinoid 20 and manganin 30.

As the proportions of these alloys is varied by different manufacturers, the figures given are but approximate. For example, if the platinum silver alloy were platinum 50 and silver 50 parts, its relative resistance would be about 20

as compared with copper, or more nearly that of platinoid.

Of the above alloys, manganin seems to be the most favored by manufacturers of high-class instruments, although platinoid is preferred by some.

**Glass Slab Resistances.** It often becomes necessary to use a high resistance for testing purposes when none is at hand. A ground glass slab covered with lead pencil lines will serve for temporary work.

To make one proceed as follows:

Take a slab of ground glass about 1 inch by 4 inches and drill a hole at each end large enough to receive the machine screw; at the bases of two binding posts.

Rub a soft lead pencil over the slab around these holes covering the area of a circle of one inch or thereabouts. Blow off the dust and lay a few strips of tin-foil over the holes nearly covering the lead pencil c rcles. Slip a washer over one machine screw and also a few wa hers of tin-foil and insert the screw in the hole from the plain side of the glass. The screws should penetrate the tin-foil on top of the glass also. Then screw down the binding post.

The tin-foil below the slab acts as a cushion between the washer and the glass. That on top of the slab also acts as a cushion, but it ensures a better contact between the binding post and pencil circle.

A similar binding post is to be fitted at each end of the slab.

Now draw a few lines joining the pencil circles. Measure the resistance of this penciled path. To lower its resistance rub on more pencil lead between the circles. To raise its resistance, rub out some of the lead. Of course all dust should be blown off.

The object of the circles was to give a point of junction between the lines and binding posts.

Resistance slabs as above may be varnished or covered with insulating compound if desired. But pencil lead or plumbago being carbon is extremely erratic in the matter of maintaining a given resistance.

**Galvanometer Shunts.** As in most cases it is not desirable to permit the entire current used in a test to flow through the galvanometer, part of it is shunted or caused to pass around the latter.

A shunt bears a definite ratio to the resistance of the galvanometer, being generally adjustable to $\frac{1}{9}$, $\frac{1}{99}$, or $\frac{1}{999}$, of its resistance so that $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ part of the current only passes into the galvanometer.

Fig. 17 shows the connections of the shunts $S$ and galvanometer $G$.

The degree in which the shunt increases the

range of deflection of a galvanometer is termed its multiplying power.

If one-tenth of the current flowing went through the galvanometer and nine-tenths through the shunt, the current in the circuit would be actually ten times that through the galvanometer.

The current therefore in the galvanometer must be multiplied by the multiplying power of the shunt to show its true value in the circuit.

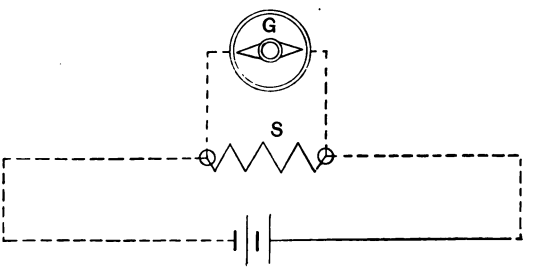



FIG. 17.

In order to find the resistance necessary in a shunt to be used with a certain galvanometer, the resistance of the latter is to be divided by the multiplying power desired less one.

As an example, let a shunt be needed for a galvanometer of 2000 ohms resistance where only one-fifth the total current is to pass through the galvanometer. This would equal a multiplying power of 5; then $\frac{2000}{5-1} = 500$ ohms.

**Formula.** Let $G$ be resistance of galvanometer, $n$ be multiplying power of shunt; $S$ resistance of shunt; then $S = \frac{G}{n-1}$.

To find the multiplying power of a shunt of given resistance add its resistance to that of the galvanometer and divide the answer by the resistance of the shunt.

For example, galvanometer is 10,000 ohms, shunt 1000 ohms, 10,000 + 1000 = 11,000, divided by 1000 = 11, the multiplying power of the shunt.

**Formula.** Let resistance of galvanometer be $G$ and shunt $S$; then $\frac{G+S}{S}$ = multiplying power.

Shunts should be connected to the galvanometer by wires of ample size, no undue resistance should be introduced by the connecting wires.

It is a good plan always to use the shunt of greatest multiplying power at first and reduce as occasion requires. Otherwise a heavy current in the galvanometer might injure suspension.

**Condensers.** The modern condenser is but a handy form of the Leyden jar; it consists of leaves of tin-foil alternating with insulated paper, mica, glass, etc., insulation between the tin-foil layers being of prime importance.

The layers are built up as follows, Fig. 18: First a sheet of insulation $A$ (or dielectric), then a sheet of tin-foil $B$ projecting at one end; another sheet

of insulation *C* and the next sheet of tin-foil *D* projecting at the other end.

Sheet after sheet is built up, Fig. 19, until the desired number is obtained, the whole mass then being subjected to immersion in paraffin or other insulator and kept under heavy pressure until set.

The portions of tin-foil projecting from one end being pressed together form one connection, the ends at the other being the second connection.

This results in every other sheet of tin-foil being connected, in fact the condenser can be considered

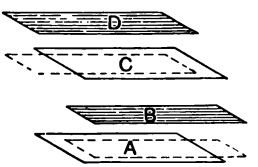



FIG. 18.

FIG. 19.

as being made up of two large sheets of tin-foil highly insulated from each other.

Condensers are made up with many different dielectrics, mica being one of the best for testing purposes. Tin-foil is most always used for the metal plates.

Adjustable condensers permit of their capacities being varied by means of plugs which cut in or out of multiple, portions of the foil sheets. In Fig. 20 is the diagram of an adjustable condenser.

*C C* are the tin-foil sheets, *B B* brass strips which carry the terminals or binding posts.

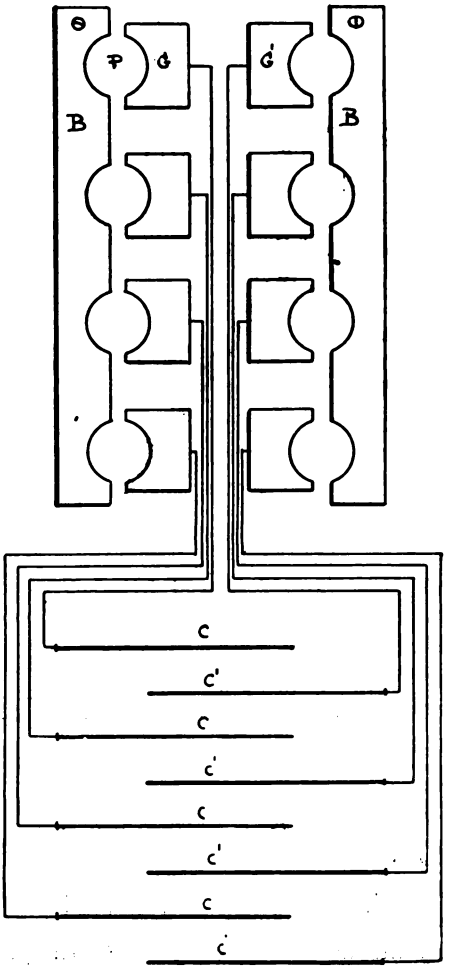



FIG. 20.

The tin-foil sheets are connected to brass blocks *G G* in such proportion of the total number in the condenser as desired.

By inserting taper brass plugs in holes between the brass strips and blocks as at *P* various combinations may be made.

A standard adjustable condenser is arranged so that the pairs of foil sheets may be connected in multiple as above, or in series.

**Keys.** In electrical testing various kinds of switches or keys are used; for opening or closing a circuit, for short circuiting, for ground connection and for reversing the direction of current flow.

The insulated parts are made of hard rubber, contacts being equipped with platinum.

In order to ensure the greatest possible insulation, the hard rubber pillars are often encircled by grooves.

This decreases the leakage from dampness as it increases the distance between the conductor supported and the table, measuring up the surface of the pillar.

**Reversing Key.** A reversing key, Fig. 21, is used to reverse the direction of current flowing into the galvanometer. Two spring brass levers *A B* provided with hard rubber knobs are connected by means of binding posts to the galvanometer *G*. A brass strip *O* carrying platinum con-

tacts bridges the levers and a similar brass strip $U$ passes under them.

The battery is connected as shown, one terminal to the lower strip and the other terminal to the upper strip.

When both $A$ $B$ are up they make contact with $O$, and form a short circuit to the galvanometer $G$, and likewise when both levers are held down on strip $U$.

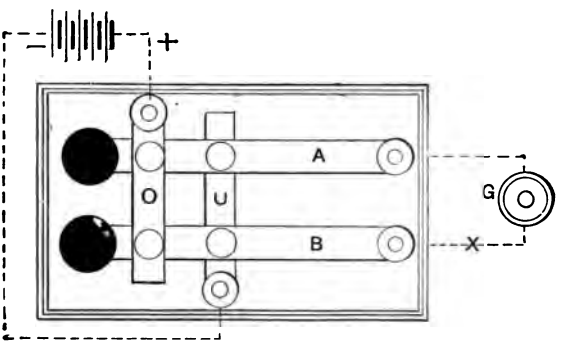



FIG. 21.

But if one lever $A$, for example, be pressed down the negative terminal of the battery is connected to $A$ and the positive terminal to $B$ and thence to the galvanometer.

On the other hand, if $B$ only is pressed down the current to $G$ is reversed because $B$ is now connected to the negative terminal of the battery and $A$ to the positive.

This key should not be so connected that the

platinum contacts form part of a circuit, the resistance of which is being measured. The contact resistance will vary as it is not possible to hold a spring key down with an unvarying pressure.

It will be seen that under no circumstances should the battery be connected to the terminals

FIG. 22.

at the end of *A* and *B*, a short circuit of the battery would result.

The Rymer Jones reversing key shown in Fig. 22 makes a rubbing or wiping contact. The levers moved by the hard rubber handles are equipped with large contacts of platinum.

The contacts on which these levers work are also faced with platinum.

A rubbing contact of this nature ensures but a nominal resistance. In fact, it can be neglected in ordinary operations.

Keys of this style of construction are always preferable to those with striking contacts.

FIG. 23.

**Commutator.** A form of reversing switch or commutator is shown in Fig. 23. By changing the plugs into different holes, circuits connected to the commutator may be reversed, put to earth, or short circuited.

The brass pieces are mounted on hard rubber pillars to increase the insulating distance from each other and from the base.

**Discharge Key.** A discharge key of the Kempe pattern, Fig. 24, has two triggers controlled by buttons. One button is marked "insulate," the other "discharge."

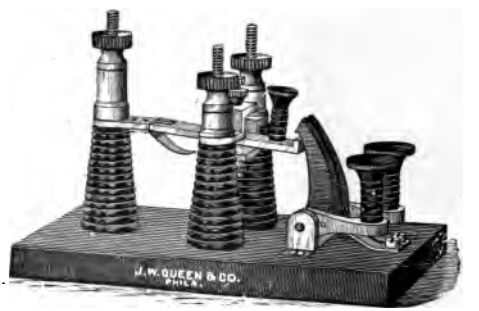



FIG. 24.

There are three binding posts, one connected to a movable lever operated by a button, one to a contact underneath this lever, and one to a contact over this lever.

When the lever is up, it presses against the upper contact completing a circuit connected to the lever binding post and top contact binding post.

When the lever is down, it presses against the lower contact; the circuit is now through the lever and lower contacts and their respective binding posts.

But in certain tests it becomes necessary to leave open the circuit connected to the lever.

The key provides for this in its second operation as follows:

Depress lever all the way down and it locks under a trigger controlled by the " insulate " button. Lower contact and lever are together. Press " insulate " button and lever flies up. But not all the way, it is caught and held in mid-air by the trigger attached to the " discharge " button. The circuit attached to the lever is thus broken.

Third, press " discharge " button and lever being released rises and rests against top contact.

**The Standard Cell.** A standard cell is a battery cell used in testing which maintains a steady e.m.f. of known value. It is used principally for comparison of other cells and to check voltmeters.

A standard cell is not required to give a large current, in actual work the current flow is kept as low as possible.

A standard cell has a thermometer included in the case as a small correction must be made for changes of temperature.

For tests not requiring extreme accuracy, the Daniel or copper sulphate cell may be used. Its e.m.f. is so near one volt as to be usable as such. A number of Daniel cells carefully set up and connected in series may be measured as to e.m.f. and the reading used for tests.

But for accurate work the Clark or the Weston cell is necessary.

The Clark cell has a positive element of mercury and a negative element of zinc sulphate and mercurous sulphate. Platinum electrodes form the connections in these elements. The e.m.f. at 15° C. is 1.434 volts.

FIG. 25.

The Weston cell, Fig. 25, has a positive element of mercury also, but the negative element is cadmium amalgam in a saturated solution of cadmium sulphate. Its e.m.f. is 1.019 volts.

The actual construction of standard cells may be found in any of the large works on testing.

# CHAPTER IV.

## VOLTMETERS AND AMMETERS.

**The Voltmeter.** A voltmeter is merely a galvanometer of high resistance connected across two conductors of opposite polarity.

The resistance of the voltmeter is extremely high in comparison with that of the conductors, and but a minute current flows through it.

As this resistance is fixed the only way to vary the amount of current flow is to vary the e.m.f.

An increased e.m.f. will increase the current flow and likewise a decrease of one will produce a decrease of the other.

And these current variations producing corresponding deflections of the needle, the deflections show actually the changes of e.m.f.

The scale divisions are calibrated or given a value in volts either by using e.m.fs. of known value, or by means of a standard voltmeter.

Voltmeters are connected across the circuit as in Fig. 26.

**The Series Ammeter.** There are two classes of ammeters, the series and the shunt.

In the former the *entire current* to be measured passes through the coils of the instrument, Fig. 27, and its changes of value directly affect the needle as in the simple galvanometer. Changes of e.m.f. will therefore not affect the ammeter directly but only in that they vary the current flowing in the circuit in which the ammeter is connected.

Series ammeters are unwieldy for large currents as will readily be seen, for the coils must be large enough to carry all the current of the circuit. They are therefore almost entirely displaced by the shunt ammeters.

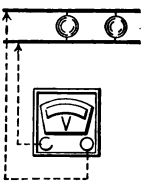


FIG. 26.

**The Shunt Ammeter.** The shunt ammeter is really a voltmeter calibrated to read in amperes and dependent upon the changes of e.m.f. in a portion of the circuit.

The current in a circuit of given resistance is controlled by the e.m.f. at its terminals.

Ohms law teaches that the current or $I$ equals the e.m.f. or $E$ divided by the resistance or $R$, as a formula $I = \frac{E}{R}$.

If then there is an increased current flow in a circuit it must be due to an increased e.m.f. unless the resistance is changed.

By taking a portion of the circuit and connecting a voltmeter across it, the variations of e.m.f. causing the current flow will be indicated.

In the shunt ammeter, Fig. 28, a German silver shunt *S* or one made of a special alloy is connected in series with the main circuit *A B*.

A low reading voltmeter *A* is connected to the opposite ends of the shunt.

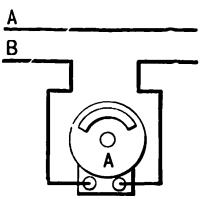



FIG. 27

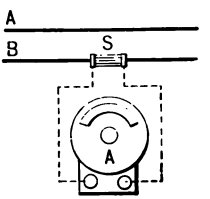



FIG. 28.

Variations of e.m.f. across the terminals of *S* will affect *A*, which is calibrated in amperes by comparison with a standard or by calculation.

**The Weston Voltmeter.** The principle of the Weston voltmeter or ammeter for direct current is that of the D'Arsonval galvanometer. The moving coil is mounted on pivots between jeweled centres instead of being suspended from wires or threads. This mounting permits of portability and compactness.

The construction of the moving system and magnet pole pieces is shown in Fig. 29.

The portable type of Weston voltmeter and ammeter is shown in Fig. 30.

FIG. 29.

In the portable instruments the data of resistance, etc., will be found printed on the inside of the lid. Care should be taken not to interchange

the case lids, each instrument bears a serial number.

The laboratory type, Fig. 31, has a very large scale of peculiar design, Fig. 32, which admits of readings being made to a fraction of one degree of deflection.

Types of Weston switchboard instruments are shown in Figs. 33 and 34, the latter being made to fit flush with the face of a switchboard.

FIG. 30.

Figs. 35 and 36 show forms which have transparent dials illuminated from behind.

Instruments of this pattern are often mounted on a swinging arm that they may be read from various parts of the room.

A black disc controlled by a button in the middle of the case front, is set to a determined point.

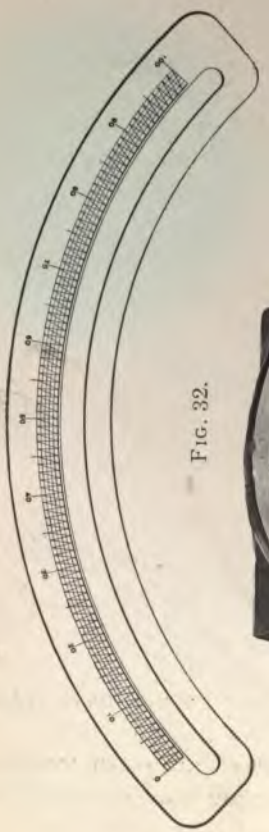


FIG. 32.

FIG. 31.

The pointer is then more readily located as to its proximity to this disc when viewed from a distance.

**Sensibility.** In the Weston direct current instruments of the portable or the Type *B* form, a resistance of about 100 ohms per volt is added.

In the other types of switchboard voltmeters the resistance is usually about 65 ohms per volt.

FIG. 33.

In case the exact resistance is not marked, it can be obtained from the makers by quoting the serial number of the particular voltmeter.

As the figures are needed in testing work, they should always be recorded.

The sensibility of a Weston instrument type B or of the portable form is about 10,000 ohms. One

scale division of deflection represents one volt through 10,000 ohms if 100 divisions equal one volt through 100 ohms.

The current used will equal the voltage indicated divided by the resistance of the instrument. For example, in a 150 volt voltmeter of 15,000 ohms, $\frac{150}{15000} = \frac{1}{100}$ ampere for full scale deflec-

FIG. 34.

tion. One scale division here representing one volt would equal $\frac{}{15000}$ of an ampere.

**Switchboard Type.** The energy necessary to operate the Weston switchboard type does not exceed .05 of one per cent. of the total energy being measured.

WESTON STATION VOLTMETER.
No.
MADE BY
WESTON ELECTRICAL INSTRUMENT CO.
NEWARK, N.J. U.S.A.

FIG. 35.

WESTON STATION AMMETER.
No
MADE BY
WESTON ELECTRICAL INSTRUMENT CO.
NEWARK, N.J. U.S.A.

FIG. 36.

As an example of close reading, a change of 1 ampere may be detected on an instrument reading to 1200 amperes at any point in the scale.

Most switchboard instruments are calibrated for a temperature of 90° F., the error amounts to one per cent. for a change of 10° F. above or below 90°.

The resistance of the coils will be increased by a

FIG. 37.

rise and decreased by a fall of temperature. The instrument therefore reads lower for an increase of temperature than the actual e.m.f. and vice versa.

**Duplex Instruments.** Most of these instruments, Fig. 37, consist of a voltmeter and an ammeter combined in one case.

But if desired two voltmeters or two ammeters may be so combined.

They are most suitable for automobile and motor switchboard work, being constructed to stand a maximum of vibration.

In connecting up automobile instruments where the wires run under the mat, some precaution must be taken against injury to the wire. The customary slipshod manner of pulling a flexible wire beneath the mat where it is forever being abraded, is to be condemned.

No instrument will indicate correctly with poor connections and this is particularly true of shunt ammeters.

Any change in resistance of the wires between shunt and instrument will affect the readings.

**Potential Indicators.** These instruments are so constructed as to give large indications for slight changes of current or e.m.f.

In order to keep the scale within limits, the pointer does not move until the e.m.f. (for example) is near the average. In Fig. 38 is an illustrative scale for an e.m.f. of 500 volts.

The index or pointer commences to move as soon as the e.m.f. increases above 400, reading e.m.f. on lower scale.

The upper scale with central zero shows the number of volts above or below 500 as it will be seen that adding the upper left scale reading and that on the lower left scale directly underneath it, the

total will be 500. And subtracting the upper reading from the lower reading on the right scale also gives 500.

**Differential Voltmeters.** Differential voltmeters have a central zero and are used in connection with two independent sources of e.m.f.

In the case of two generators which are to be run in parallel, the generators are adjusted until the needle stands at zero, when the e.m.fs. of both

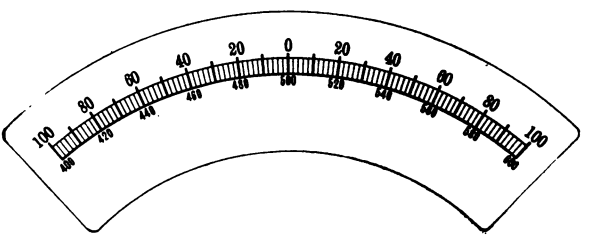



FIG. 38.

are equal. The needle points towards the side of higher e.m.f.

When the two generators are being operated, the readings on either side must not be taken to represent the e.m.f. of that particular generator. The readings indicate the difference between the generators.

**Double Scale Instruments.** Indicating instruments are provided with double scales so that a greater range of measurement is possible.

For example, the upper scale might read from 0 to 150 volts and the lower scale from 0 to 15 volts. In this case as the instruments are all direct reading with deflections proportional to the current, the resistance put in circuit for the higher reading would be ten times that for the lower.

There are generally two marked binding posts on one side and one on the other. Care must be taken to connect to the correct posts. In an instrument at hand, the same scale reading to 6 volts has three readings. The 6 volt total scale has 521.6 ohms in circuit with the coil, the 60 volt = 5215 ohms and the 240 volt = 20869 ohms.

A simple calculation will show that all these resistances are almost exactly proportional to the total scale readings.

**Multipliers.** Multipliers for increasing the readings of voltmeters are largely used. They are resistance coils in portable cases, Fig. 39, and are put in series with the voltmeter.

Multipliers must be adjusted for each particular instrument as the resistance coil must be a multiple of the voltmeter resistance. A multiplier with a value of 10, for instance, used with a 6 volt voltmeter of 521 ohms would measure about 5215 ohms; one with a value of 40 would equal about 20,860 ohms. The multiplier by 10 would give a total scale value of 60 and the multiplier by 40, a total scale value of 240 volts to the 6 volt instrument.

The value of such an apparatus in practical work is very great. It does away with the necessity of having a number of voltmeters of different ranges.

FIG. 39.

**Millivolt and Milliampere Instruments.** The prefix milli means one thousandth, a millivolt is an e.m.f. of one thousandth of a volt, a milampere or milliampere, one thousandth of an ampere.

Instruments of which the total scale reading is about one volt or one ampere, and those in which each scale division represents one thousandth of a unit, are millivoltmeters or milammeters respectively.

Such instruments are of the utmost service in measuring low resistances, temperature changes,

FIG. 40.

etc., and their use will be described in the chapter on testing.

**Relative Sizes.** Fig. 40 embodies the relative sizes and styles of Weston instruments with their style letters.

**Hot Wire Instruments.** Voltmeters and ammeters indicating from the expansion and contraction of wires carrying current were first represented by the Cardew types.

A fine wire was run over a pulley carrying an index, one end of the wire being rigidly attached and the other end held taut by a spring. When current passed along this wire, the latter expanded, the slack was taken up by the spring and the pulley rotated. Upon cessation of the current, the wire cooled and contracted, the pulley reversed and its pointer returned to zero.

Instruments made on this principle could be used on either direct or alternating currents.

But they possessed the disadvantages of burning out on accidental overloads, of the wire becoming stretched or otherwise distorted, of consuming a larger current than the other types which would render them less accurate, of requiring a long case and an undesirable position of that case and many minor defects.

**The Whitney Hot Wire Instruments.** The Whitney type of hot wire instruments represents the practical solution of the before mentioned defects.

The mechanism is shown in diagram in Fig. 41.

A wire *A B* of high resistance, low temperature

coefficient and non-oxidizable metal is secured at one end to a plate *C*. It runs over a pulley *D* mounted on a shaft *E*, and its free end is attached to the other end of *C*, but is insulated therefrom. A spring *F* keeps the wire taut and takes up any slack imparted to the wire by the passage of current.

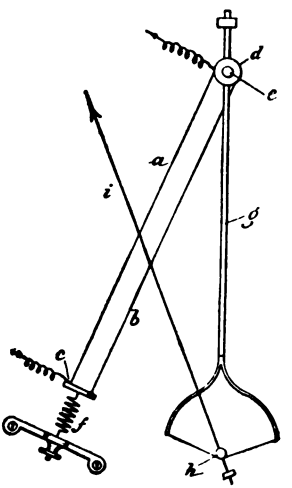



FIG. 41.

Current only flows in the portion of wire *A* between C and the pulley *D* where the coiled wire connection is shown.

When *A* is heated by current flow it expands, *F* taking up the slack, pulls *A* round *D*, and rotates *D* and *E*.

If a pointer were directly attached to shaft $E$ it would indicate on a scale the movement of $D$ and $E$.

But a magnifying device is employed. $G$ is a forked rod rigidly attached to $E$, at its lower end a silk fibre fastened between the forks passes around a pulley $H$ which carries the pointer.

FIG. 42.

The rotating of $E$ therefore moves $G$ and the silk fibre rotates $H$ and the pointer, thus magnifying the movement of $G$.

Any temperature variations will affect $A$ $B$ equally, it is therefore self-compensating.

The tension of $F$ being slight, wire $A\ B$ is not under a heavy strain, it more nearly returns to its original length after current ceases.

The instrument, however, can be adjusted to zero very readily if it should become necesssary.

A portable instrument is shown in Fig. 42 and

FIG. 43.

a switchboard instrument in Fig. 43, many other types being manufactured.

For direct current work only an electro-magnetic system is used. The ammeters of this type have a uniform drop of .05 volt. Shunts are thus interchangeable.

**Ammeter Shunts.** The ammeter shunts used with Weston switchboard instruments are shown in Fig. 44.

The shunt itself is made of one or more sheets of alloy resembling German silver in appearance. The ends of these sheets are fastened into brass or copper blocks.

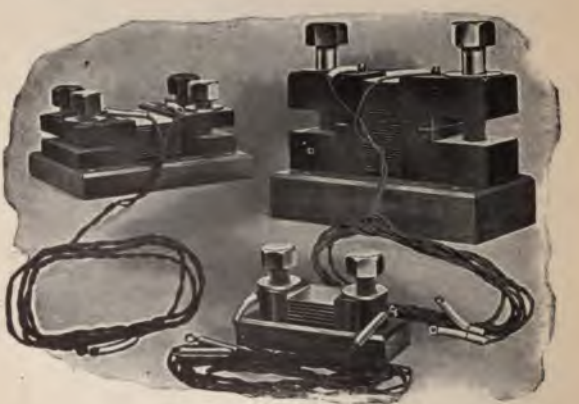


FIG. 44.

Large clamping screws are provided for attachment of the shunt to the bus-bar, which latter are inserted in the large slots at each end of the shunt. The small screws are for the instrument cords.

The Whitney shunt, Fig. 45, is made of a solid block of metal slotted as shown so as to give the resistance of a long bar.

In all cases the connections to shunts must be

as perfect as possible. Poor contact causes heating if at the bus-bar connections and thereby incorrect indicating at the instrument terminals.

The shunt cords must also be properly clamped or incorrect readings will result.

The importance of these precautions will be thoroughly appreciated when the principle of the shunt ammeter is considered.

For the same reason the cords must on no account be tampered with. If too long loop them up and

FIG. 45.

bind the looped part if desired with tape. A shortened cord would increase reading of instruments as it lowers the resistance in series with the ammeter. And a poor connection would decrease readings on account of its resistance.

Too little attention is often given to these points by those in charge of a plant, an instrument cannot give correct readings if improperly connected.

Shunts for portable instruments are included in the base of the instrument.

For extreme adaptability, a millivoltmeter can

be equipped with a set of shunts so that the same instrument will measure from a fraction of an ampere to many thousand amperes.

**Other Types of Instruments.** Voltmeters and ammeters are constructed on principles other than that of the D'Arsonval galvanometer, or the stretching of a hot wire.

It is unquestioned that the D'Arsonval system is the only correct one for instruments to be used *on direct current circuits only.* But owing to patent rights it has been necessary for manufacturers to seek other methods of construction.

The result is that while no new principles are used, those less suitable than the D'Arsonval have been perfected with such ingenuity as to make most excellent substitutes.

It is also unquestioned that when the D'Arsonval patent expires it will be the only principle that will survive. That is, unless the electrostatic instruments are much improved and made practicable for measurements of low potentials. The above refers more to laboratory and portable instruments than to those designed for switchboard work.

The solenoid type of Fig. 46 has a pivoted soft iron armature curved to enter a solenoid. Current being passed through the wire of the solenoid causes the armature to be attracted more or less against a restraining force. The latter may be gravity or springs.

A pointer attached to the armature indicates on a dial.

A simpler solenoidal instrument is shown in Fig. 47 but acts in the same manner.

A type of magnetic vane instrument, Fig. 48, depends upon the repulsion between two pieces of iron in the same field. One is stationary inside a coil of wire, the other is movable on an axis.

As both lie in the coil the same way they both

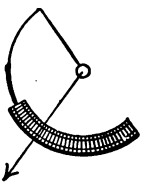


FIG. 46.

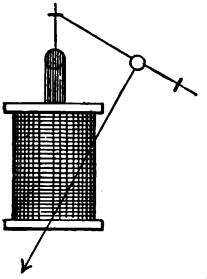


FIG. 47.

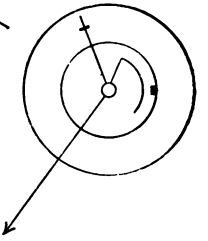


FIG. 48.

have $N$ poles or $S$ poles at the same end. As similar magnetic poles repel each other the stronger these iron pieces become magnetized the farther apart they move.

The galvanometer principle, Fig. 49, is used where a short magnet is pivoted inside a coil large enough to give a fairly uniform field.

In Fig. 50 the attraction is between two curved armatures and the two poles of an electro magnet.

This is purely magnetic attraction and is counterbalanced by the force of gravity, a spring, or an adjustable weight.

The heating effects of current are used in Fig. 51 where a coil of wire surrounds a thermometer bulb. By the rise of the mercury the heat and thereby the current flow is measured.

**Westinghouse Type K.** The Westinghouse type K voltmeters and ammeters are made on the prin-

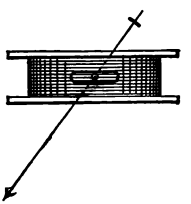


FIG. 49.

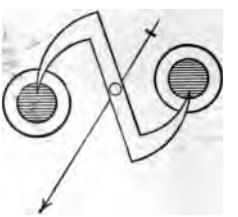


FIG. 50.

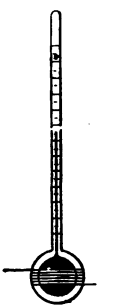


FIG. 51.

ciple illustrated in Fig. 47, the lower end of the armature working in a glass tube filled with oil. This steadies the moving system and renders it dead beat. The armature is not rigidly attached to the pointer shaft, but has a flexible connection of silk. The shaft itself takes the form of a scale beam working on knife edges. The bearings for the knife edges are so constructed that the leverage

becomes uniform and the divisions remarkably even throughout the scale.

Being purely electromagnetic attracting instruments they can be used on circuits of either direct or alternating current.

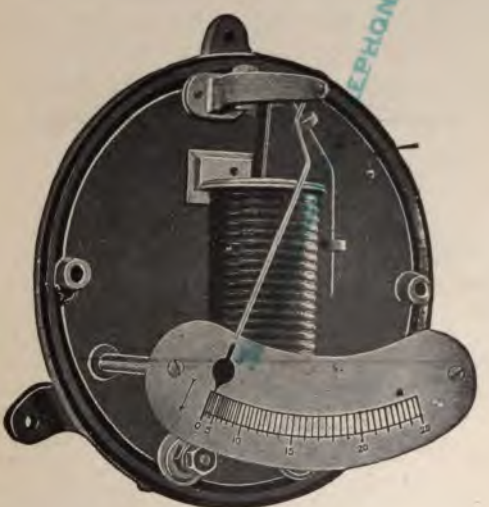


FIG. 52.

**G. E. Potential Indicators.** A simple form of voltmeter and also of ammeter made by the General Electric Company is illustrated in Fig. 52. The movement of the armature in the solenoid is controlled by gravity, means of adjustment being by means of the balance weights shown in the illus-

tration. The ammeters of this type are series connected not shunted.

**Thomson Inclined Coil Meter.** The Thomson inclined coil ammeter is adapted for use on circuits of alternating current.

The instrument is constructed on the magnetic vane principle in which an iron vane or wing strives to turn itself parallel with the axis of a coil carrying the current to be measured.

FIG. 53.

The name comes from the peculiar position of the coil. Instead of lying flat on the base its axis is inclined.

A soft iron vane is mounted obliquely on a shaft which latter is held in a vertical position and controlled by springs.

The shaft also carries a pointer moving over a graduated dial.

When current is sent through the coil the vane turns against the springs so as to set itself parallel with the axis of the coil. The inclined position of the latter and the peculiar shape of the vane give a more evenly divided scale than is obtained in most other instruments of this class.

FIG. 54.

The voltmeter has a similarly placed stationary coil, but in place of the iron vane is equipped with a moving coil in series with the other coil.

The pointer is carried by the moving coil system which is controlled by springs.

This type of instrument can also be used on direct current circuits.

On alternating current circuits they work equally well for all frequencies of alternations.

The mechanism of the pocket ammeter is shown

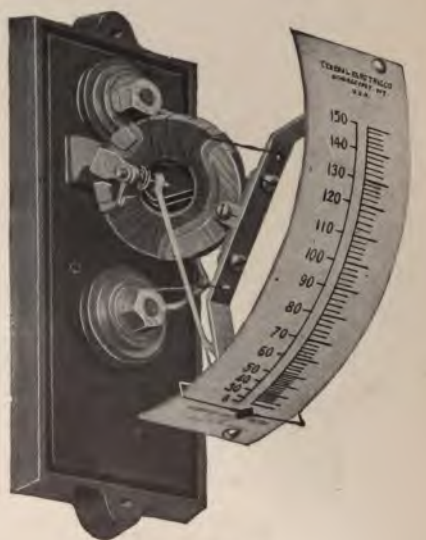



FIG. 55.

in Fig. 53, the switchboard ammeter in Fig. 54, and the switchboard "edgewise" voltmeter with iron vane moving system in Fig. 55. The ammeters below 500 amperes total scale are series, the entire current passing through the instrument.

Although the above type may be used on direct

current circuits, the manufacturers recommend the Thomson astatic form for such circuits.

**The Thomson Astatic Voltmeter.** The mechanism is illustrated in Fig. 56, the same principle being used in the astatic ammeter which, however, is a shunt instrument.

The pointer shaft carries a coil through which

FIG. 56.

passes the current to be measured and also two pieces of magnetic metal.

The field magnets are electromagnetic, not permanent, as in the D'Arsonval instruments.

An astatically arranged magnetic field is mount-

ed perpendicularly to the shaft and restrains the pieces mounted on the shaft.

Deflections of the coil due to current flowing through it are opposed by the magnetic field acting on the pieces of metal which are carried by the same shaft. There are thus no restraining springs, current to the moving coil being conveyed by torsionless spirals of silver wire. The illustration shows the illuminated dial voltmeter one of the miniature lamps for lighting the dial being visible. The resistance spools are also shown, two on each side of the electromagnet coils.

The dead beat or damping effect is produced by an aluminum disc which moves in the field of an electromagnet.

Thomson astatic instruments can be provided with polarity indicators, a red disc showing in the scale card when polarity is reversed.

**The Wattmeter.** The most efficient forms of wattmeters are constructed on the electro-dynamometer principle.

If two coils of wire are constructed, one stationary and the other free to turn inside it, the movable one will tend to turn until its coils are parallel with the stationary one when current is applied to both.

In the wattmeter, the stationary coil is of heavy wire and the main current flows through it. The movable coil is of fine wire in shunt across the circuit.

Changes of current strength in the main circuit thus affect one coil, and changes of e.m.f. the other.

As the watt is the product of the e.m.f. multiplied by the current, the index attached to the movable coil is influenced by the watts in the circuit.

This type of instrument can be used on direct or alternating current lines.

**Keystone Instruments.** The Keystone voltmeters at present are made either on the electro-dynamometer principle just described, or are electromagnetic.

In both types they can be calibrated to read on alternating or direct current circuits.

The makers recommend the electro-dynamometer type for direct current voltmeters, but not for ammeters. The connections between the moving coil and the circuit would have to be so large as to interpose friction.

The ammeters are electromagnetic and are for series connection. The scales, however, are remarkably even.

In the electro-dynamometer type, there are two springs to control the moving coil.

Over the first part of the scale a spiral spring opposes the movement, while a "pendulum" spring assists it. Further on, the latter spring assists the spiral spring, thus opposing the coil movement when the deflecting force is greatest.

This ensures greater evenness in the scale divisions throughout the range.

**Queen Instruments.** The Queen Wirt voltmeters and ammeters can be used on circuits of either direct or alternating current.

They are electromagnetic, the principle being that in which an iron armature tends to move into the strongest part of a magnetic field.

A tube of soft iron lies parallel with the axis of a coil of wire through which current passes. Being mounted away from the true centre of the coil it moves towards that centre where the field is strongest.

The electromagnetic principle does not allow of absolutely even scale divisions, but those in the middle of the scale are fairly uniform.

Although for use on both circuits, the scales must be graduated for either one or the other.

For alternating current the divisions are most uniform.

In the Queen portable form, an upper scale can be graduated for direct current and a lower scale for alternating current.

**Electro-Static Instruments.** A type of instrument much used on circuits of extremely high e.m.f. is made on the principle that two oppositely charged plates will attract each other.

A movable plate of aluminum is suspended between fixed plates of similar metal. The movable plate carries an index and is controlled either by gravity or springs, generally the former.

The fixed plates are connected to one side of

the circuit and the movable plate to the other side.

The instrument in fact is a form of condenser.

When a source of high e.m.f. is connected as above to the instrument the mutual attraction between the two series of plates causes the movable plate to swing and its index to indicate on a scale.

As the attractive force depends upon the *square* of the e.m.f., the scale divisions are not uniform.

Such instruments consume no current.

The chief advantage of the electrostatic voltmeter is that it can be directly connected to a circuit of extremely high potential.

In the case of alternating current circuits with voltages up in the tens of thousands it becomes necessary with other types of voltmeters to reduce the voltage before applying it to the instrument.

This is done by means of a "potential transformer," which is a small transformer especially constructed to reduce the high voltage to a lower one suitable to the instrument in use.

The voltmeter is thus not directly connected to the circuit but is inductively connected.

**Reading Instruments—Parallax.** One source of error in reading voltmeters and ammeters lies in the fact that the pointer or index does not touch the scale.

If the eye is not directly in front of the index a reading to one side or the other is liable to be made.

Where an index stands as much as a quarter of an inch away from the scale, a large error in reading might result.

This error is called parallax and is prevented in portable instruments for accurate testing by the following device:

The index is made thin and flat, lying edgewise towards the eye. A strip of mirror is placed be-

FIG. 57.

neath the index. The reading is made when by looking down on index and mirror, the index hides its own reflection.

Some switchboard instruments are made for edgewise reading, that is, the scale is at right angles to the base, Fig. 57. The scale is curved and the index is bent so as to follow it.

In this type, the error of parallax is likely to be greater than with the ordinary type.

**Care of Instruments.** Electrical measuring instruments must be handled with at least ordinary care.

Although made as air tight as possible, dampness and excessive heat should not be permitted to attack them.

Violent swinging of a pointer through excessive current is liable to do more than bend the pointer.

Even if it does not permanently injure the instrument it does it no good. This is more likely to happen in using a double scale instrument, or by reversing the connections.

When taking measurements the instrument should not be set down on a generator or its bed plate.

And a direct current voltmeter should not be tried on an alternating current circuit.

The glass front should never be rubbed before taking a reading, or the pointer will be influenced by so-called static currents.

They may be dissipated by touching the finger to the middle of the cover, but are best omitted.

In the case of two or more compound wound generators being connected together to run in multiple, a so-called equalizer is used. This is a bus-bar or cable connecting together a point on each dynamo between the series field winding and its brush connection.

The ammeter or its shunt is not to be connected in series with the lead from the series field or equalizer side, but in that lead which runs directly from the brush to the main switch or bus-bar. Otherwise current flowing in the equalizer bus would not be indicated.

Ammeters for storage battery circuits are made with a central zero as the deflections of charge or discharge are in different directions.

This is of course only true of that class of instrument in which the direction of deflection depends upon the direction of current flow, that is, polarized instruments.

If a polarized instrument without a central zero be used for storage battery work, a reversing switch becomes necessary between the shunt and the ammeter.

This is but a makeshift and is by no means to be recommended.

Any instrument built to be used only in a vertical position must not be used when laid horizontally and vice versa. Readings may be made, but they are liable to be inaccurate, owing to friction or gravity.

# CHAPTER V.

## THE WHEATSTONE BRIDGE.

**The Wheatstone Bridge.** In Fig. 58 is shown the lozenge or kite diagram of the Wheatstone bridge.

$A$ $B$ are two adjustable resistances. These form the proportional arms of the bridge.

$R$ is an adjustable resistance or rheostat, $G$ a galvanometer, $B$ the battery and $K$ $K$ keys closing the battery or galvanometer circuits respectively. $x$ is a resistance which it is desired to measure.

If the battery key be closed, current will divide between $A$ and $B$ and flow through $R$ and $x$ back to battery $B$.

If $A$ $B$, $R$ and $x$ are equal, the current will divide equally down each side of the lozenge. Even if the galvanometer key be closed, no current will flow into $G$.

If $x$ be greater in resistance than $R$, part of the current through $B$ will travel through $G$ and thence through $R$ in accordance with the law of shunts. The galvanometer needle is thus deflected. But by adjusting $R$ to agree with $x$ the two paths $R$ and $x$ being equal no current flows through $G$.

Should $R$ be greater than $x$, current flows through

$A$ and through $x$ by way of the galvanometer, and the needle is deflected, but in the opposite direction to the former case.

The Wheatstone bridge is based on the fact that no current flows between points of equal potential.

Consider the two sides of the bridge $A\,R$ and $B\,x$ as two wires of equal resistance per unit length in multiple between the battery terminals.

The drop of e.m.f. will be the same in each wire for the same length.

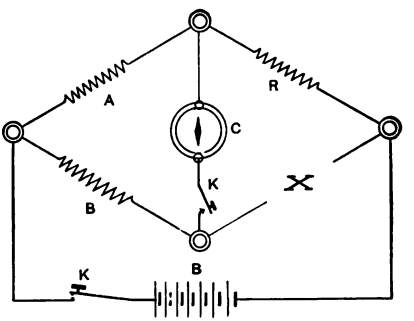



FIG. 58.

If the galvanometer be connected to a point in each wire equally distant from either end, say the middle of each, no current will flow in the galvanometer.

The effect is the same as if both terminals of the galvanometer were placed on the same spot in a single wire carrying current.

Shift one galvanometer connection, this has the

same effect as separating the two contacts on a single wire.

The galvanometer in the latter case will be in shunt with the piece of wire included between its contacts. As the points are at a different potential, the galvanometer will show the potential in that piece of the circuit.

The same applies to the double wires. When the bridge galvanometer is connected as in the figure but assuming $A$ $R$ $B$ and $x$ as equal, the galvanometer is connected between two points of the same potential.

If $x$ be increased in resistance over that of $R$ it would be the same as increasing the length of the wire $x$.

In the latter case the galvanometer contact could be shifted along the $x$ wire until it again stood at the middle, when the galvanometer would remain undeflected.

In the bridge the resistance $R$ would be adjusted until it was equal to $x$, $A$ being in the same proportion to $R$ as $B$ was to $x$, the galvanometer would be at the points of equal potential. Of course $B$ could be changed but $R$ is the adjustable resistance.

If $A$ is to $B$ as $R$ is to $x$, then $x$ will be the same as $B$ multiplied by $R$ and divided by $A$.

This is just simple proportion in arithmetic as the following example shows. In simple proportion, to get the fourth term or answer, the second and third are multiplied together and divided by the first.

For example, if 1 = 2 what will 4 equal?

$$1 : 2 :: 4 : x \text{ or } \frac{2 \times 4}{1} = 8.$$

And in the foregoing formula, if $A = B$ what will $R$ equal?

$$A : B :: R : x, \text{ or } \frac{B \times R}{A} = x.$$

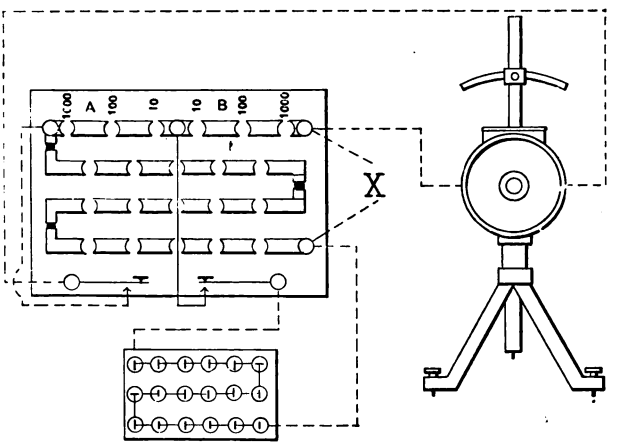



FIG. 59.

**The Post-Office Bridge.** The connection for resistance tests of the form of bridge known as the (English) Post-Office Bridge is in Fig. 59.

A tripod form of Thompson galvanometer is illustrated and an 18 cell battery but it is evident that a larger or smaller battery could be used.

And any form of galvanometer would be connected up in the same way.

The shunt is not shown, it would be connected across the galvanometer terminals. The resistance to be measured is connected at $x$.

The key on the left of the bridge is the battery key and should always be depressed first. The right hand key is the galvanometer key and is to be only tapped until a close balance is obtained. Otherwise were the bridge rheostat not adjusted to the measurement being made, the deflection would be violent.

Much damage to a galvanometer is done by neglecting this rule.

In a reflecting galvanometer where the mirror is suspended by a silk fibre, the latter may be broken. Replacing it is a work requiring expert knowledge and vast patience.

**Testing with the Bridge.** For illustration of the use of the bridge the one shown in the last figure will be selected.

Suppose it is desired to measure the resistance of a coil of wire. The two ends are bared of insulation, scraped clean and inserted in the binding posts as shown at $x$.

The other connections of the figure are already made as described. For the first test, however, it will be well to use only one cell of battery.

All plugs are in the holes in the rows of resistance coil connections.

Remove from both *A* and *B* the plugs from the 10 ohm coils.

Remove a 10 ohm coil plug from the rheostat part.

Depress the battery key and tap the galvanometer key.

The deflection is noted both as to amount and direction. Suppose it is 60° to the left.

Remove another plug say from 100 ohm coil and tap key again.

Deflection in same direction only 10°.

Remove 20 ohm plug, deflection 5° to right. This indicates that too much resistance has been unplugged.

Replace 20 ohm plug and remove 10 ohm plug, deflection is now 1° but to left.

Indicates that still too little resistance is out.

Remove 1 ohm plug; no deflection perceptible.

Then read resistance unplugged. 10 + 100 + 10 + 1 or 121 ohms is resistance of wire coil.

When a resistance equal to that being measured is unplugged, no deflection takes place.

It may be stated here that in these examples no actual statement of deflection due to resistance is meant. The values given are only illustrative.

It will be seen that the deflection is to one side when too much resistance is unplugged and to the other side when too little resistance is unplugged.

Most galvanometers fitted in the cases of portable testing sets are marked + and − on opposite ends of the scale.

As the battery is connected so as to send current always in the proper direction, a deflection to the + side means too much resistance and one to the — side too little resistance unplugged. Of course reversing the battery connections will reverse the value of these signs.

In the bridge of the instruments being described in this section, there are three coils in each arm, reading from left to right 1000–100–10 in *A* and 10–100–1000 in *B*.

At present only equal ones are used in each arm. For measuring low resistances the 10 ohm coils in each arm are unplugged. For high resistances, 100 ohm coils in each arm are used.

For very high resistances 1000 ohms in each arm.

The rule is to use the nearest bridge coils to the resistance being measured.

As the total resistance of the rheostat is in this case only 11,110 ohms, it is evident that by the method before pursued, no higher resistance can be measured and none lower than 1 ohm as that is the lowest coil in the rheostat.

**Proportional Arms of Bridge.** This is where the proportional arms of the bridge come in to use.

By unplugging a higher coil in the *B* side, the value of each coil in the rheostat is multiplied by the number of times the unplugged coil in *A* divides into that of *B*.

And by reversing this and unplugging higher in *A*, the rheostat coils are divided by the number of

times $A$ is greater than $B$. As a memory aid—$A$ divides, $B$ multiplies.

This gives new values to the rheostat coils and vastly extends the range of measurement.

For example, let $A$ be 10 and $B$ 100, then $B$ is ten times $A$; *multiply* the rheostat figures by 10.

The 1 ohm coil then becomes equivalent to a 10 ohm coil and the 1000 ohm a 10,000 ohm coil, and so on.

And let $A$ be 10 and $B$ 1000 and the rheostat is multiplied by 100, the 1 ohm coil is thus equal to 100 ohms, the 1000 ohm to 100,000 ohms.

This last setting of the arms will give a value to the rheostat of $11{,}110 \times 100$ or 1,111,000 ohms.

If then the bridge arms were so set and a balance obtained at 162 ohms, the actual resistance would be $162 \times 100$ or 16,200.

In some bridges there are 1 ohm coils, then the range will be 1000 times and $\frac{1}{1000\text{th.}}$

The dividing method or higher coil in $A$ is on the same plan.

Unplug 10 ohms in $B$ and 100 in $A$, then the readings will be *divided* by 10, which is the number of times 10 goes into 100. And the 1 ohm coil becomes $\frac{1}{10}$ ohm, the 10 ohm coil now being equal to a one ohm coil.

This proportional property of the arms not only enables larger or smaller measurements to be made

than are in the rheostat, but it gives closer readings.

Take the first example, the coil of wire. Set the bridge arms *A* 1000, *B* 10, making a division by 100 necessary of the rheostat readings. As the first test showed 121 ohms, unplug one hundred times 121 ohms or 12,100 in the rheostat.

As the bridge now stands this only equals 121 ohms. It may be necessary to increase the battery.

Having depressed the battery key, depress the galvanometer key and there will probably be a deflection one way or the other. Suppose it is to the – side.

Unplug 10 ohms now $\left(\frac{1}{10}\right)$ and try deflection. Let it take 18 ohms more to get a balance or zero on the scale.

Then the rheostat will read 12,118 which divided by 100 gives 121.18 ohms, a far closer reading than with equal arms.

It is a good plan to make a number of tests of coils of known resistance, or to check up tests by trying various combinations of the arms.

It must be remembered that as the resistance of copper increases from heat, readings will vary from time to time owing to the current flowing in the wire being tested. The relation between heat and resistance will be found elsewhere in these pages.

In testing coils, electro magnets, etc., they must

not lie near the galvanometer. Where leads are necessary from the bridge to the apparatus being tested, the leads also should be tested as their added resistance would give a false value to the test.

**Formula.** A stating of the foregoing rules as formulas will be as follows:

Let $R$ be the resistance unplugged in rheostat, $A$ that in arm $A$ of bridge, $B$ that in arm $B$ of bridge, $x$ the unknown resistance.

Then $A : B :: R : x$, and $A\,x = B\,R$; therefore $x = \frac{B\,R}{A}$.

# CHAPTER VI.

## PORTABLE TESTING SETS.

**The Willyoung Portable Testing Set—Model K.** A form of portable Wheatstone Bridge is shown in Fig. 60. It is furnished with a small battery in the case, and a set of working shunts.

The galvanometer is of the D'Arsonval type with a sensibility of one scale division for one volt through over two megohms.

It is not disturbed by the proximity of other electrical machinery or magnetic fields.

Full directions are furnished with each instrument. The general rules of its use are those for all forms of Wheatstone Bridges.

In testing a resistance with this instrument it is connected to binding posts *C D*, Fig. 61. The flexible battery cords are connected by their cup connectors to two adjacent studs on the battery. This cuts in one cell; if more are desired the cups are connected to include them in circuit.

The commutator plugs connect *A x* and *B R* as shown. Plugs *G a* and *B a* are inserted. Plug *V* is omitted, galvanometer switch is turned to " in "

and shunt switch put on *I*, that is, if the particular set is equipped with a contained shunt.

Plug all holes in the bridge arms but those corresponding to 100 ohms in each arm.

Then unplug rheostat until enough resistance is

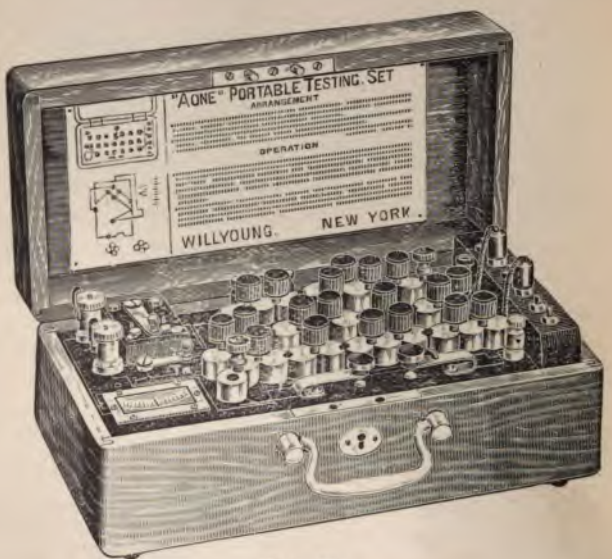



FIG. 60.

cut in circuit to equal what the resistance being measured amounts to. (When no idea is had of the latter, the galvanometer key must be tapped carefully that no undue deflection injures galvanometer).

Depress battery key and tap galvanometer key.

If needle swings to $x$, unplug more resistance. If to $-$ cut out some of the coils in the rheostat.

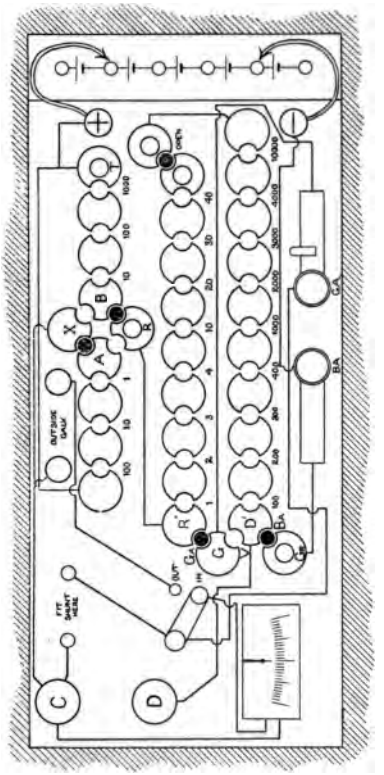



FIG. 61.

By varying the proportions in the bridge arms, higher or lower resistances than those included in

the rheostat can be measured. The latter runs from 1 ohm to a total of 21,110 ohms.

The working range of this set is from .001 ohm to about 500,000 ohms with the battery supplied in the case.

By using a larger battery connected at + and – at the right hand of the case, much larger readings may be made. And if a more sensitive galvanometer be connected where the shunt is, readings to a maximum of 21 megohms is claimed for this set.

But for such high resistance work as the latter, the direct deflection method will be found preferable.

**The Queen Portable Testing Set.** The Queen Acme portable testing set, Fig. 62, is adapted for all resistance measurements. There are three rows of brass blocks and plugs controlling resistance coils.

The middle row is the Bridge, the top and bottom rows, the rheostat.

In the centre of the Bridge is a split block commutator $R\ x$ which can be connected to the Bridge arms by plugs.

If the plugs are inserted in this commutator in the direction of arrow $L$ as shown, the resistance in the rheostat is divided by the quotient obtained in dividing the higher Bridge arm by the lower.

If plugs are in direction of arrow $H$, multiply rheostat by quotient. For example, let rheostat

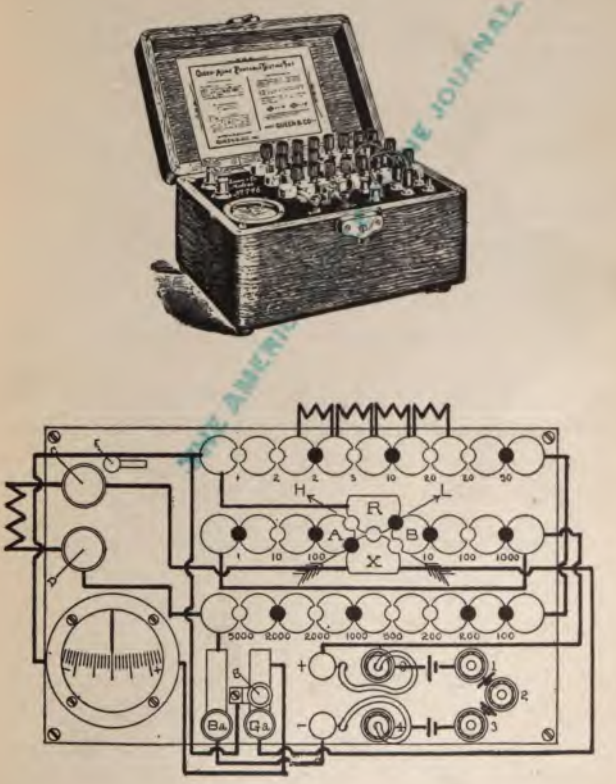



FIG. 62.

equal 100 ohms and commutator be set as in figure. 100 ohms in arm $B$ divided by 10 ohms in arm $B = 10$. Divide rheostat by 10, $\frac{100}{10} = 10$ ohms.

But let commutator be set in direction of arrow $H$. Then same example, $\frac{100}{10} = 10$, 100 ohms in rheostat $\times$ 10 = 1000 ohms.

The galvanometer scale is marked + and −. If the needle swings towards +, reduce the rheostat if to −, increase it.

The range of the Bridge arms is 1 to 1000 ohms, and the rheostat 11,100 ohms. This gives a range of testing from .001 to 11,100,000 ohms. For resistances above one megohm, however, more battery is required than will be found in the case.

**Formula.** For this Bridge, the formula for the commutator setting in direction of arrow $L$ is $\frac{A}{B} = \frac{x}{R}$, and for direction $H$, $\frac{A}{B} = \frac{R}{x}$.

The general directions for this set are similar to the regular Wheatstone Bridge tests. It is very simple and easily handled. Other adoptions of the set will be found in later pages of this book.

Table III. gives the Bridge setting for various resistance measurements. It is used in conjunction with the directions regarding the commutator before given.

TABLE III.

Showing setting of Bridge arms to measure resistances as in first column.

| "*x*" *Ohms.* | | | Ohms A | Ohms. B |
|---|---|---|---|---|
| Below | 1.5 | | 1 | 1000 |
| From | 1.5 | to 11 | 1 | 100 |
| " | 11 | to 78 | 10 | 100 |
| " | 78 | to 1,100 | 100 | 1000 |
| " | 1,100 | to 6,100 | 100 | 100 |
| " | 6,100 | to 110,000 | 1000 | 100 |
| " | 110,000 | to 1,110,000 | 1000 | 10 |
| " | 1,110,000 | to 11,110,000 | 1000 | 1 |

**Whitney Testing Set.** This portable set, Fig. 63, has 11,110 ohms in the rheostat and 1, 10, 100 and 1000 ohm coils in each arm of the Bridge.

One plug only is used in each row of the rheostat inserting the plug cuts in a resistance equal to the number marked on the block.

The battery and galvanometer keys can be controlled by one button, the battery contacts being made first. Or they can be depressed separately, as desired.

The inside connections are shown in Fig. 64.

**To Use Bridge.** Connect the terminals of the unknown resistance to the lower right hand binding posts. The terminal of the flexible cord projecting from the hard rubber top between the bridge arms should then be adjusted to one of the

Whitney Testing Set.
DIRECTIONS FOR USE.
WHITNEY ELECTRICAL INSTRUMENT CO.
LOOP
DIVIDE BY
MULTIFLY BY
GALV.
THOUSANDS
HUNDREDS
TENS
UNITS

FIG. 63.

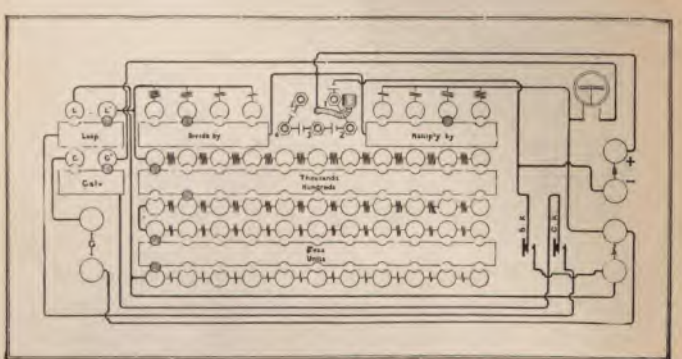

Loop
Galv
Divide by
Multip'y by
Thousands
Hundreds
Tens
Units

FIG. 64.

five posts, likewise so located; thus throwing in circuit from one to five cells of battery, as will be seen by the diagramatic illustration herewith.

If more battery power is needed remove the flexible cord terminal from the post and attach the terminals of an external source of direct current to the binding posts *B B*, the positive terminal being attached to the post marked " + ."

This external e.m.f. should not exceed 15 volts.

Assuming that nothing is known of the magnitude of the resistance to be measured, insert the plug in the bridge arm lettered " multiplied by " in the gap numbered " 100 " and the plug in the bridge arm " divide by " in the gap numbered " 100." Place the plug in the " hundreds " row in the gap numbered " 1." The three remaining plugs numbered " 0 " in their respective rows. This act has inserted 100 ohms in the rheostat arm of the bridge.

Depress the combination key momentarily.

If the galvanometer needle deflects towards " – " the rheostat resistance is too small and more should be added by moving the plugs along.

If the deflection is towards " + " the rheostat resistance is too much and less is to be substituted by putting the " hundreds " plug into its " 0 " gap and moving the " tens " plug along.

Proceed in this manner until some combination of coil values is found where the galvanometer needle will no longer deflect when the key is depressed.

The value of the unknown resistance is then indicated by the position of the rheostat plugs.

The above applies only where the unknown resistance has a value between 1 ohm and 11,110 ohms.

If the resistance is lower than 1 ohm insert the plug in the left hand ratio arm into "10" and the right hand ratio arm plug into "100" or "1000." Balance may now be obtained as before, then

$$R \frac{\text{Multiply by}}{\text{Divide by}} = X \text{ or } \frac{B}{A} R = x.$$

For resistances higher than 11,110 ohms the plug in the left hand bridge arm must be inserted in a higher number than the plug in the right hand bridge arm.

When using the set for the Varley loop as a Wheatstone bridge see that the plug in the "loop" bar is in block marked "V. & B." When using set for Murray loop test shift the plug into block marked "M."

The lower right hand binding posts are used for all measurements with this set.

The upper right hand binding posts are for extra battery.

If an external galvanometer is to be used, it is to be connected to the left hand binding posts. The plug is shifted from the right hand hole in block marked galv. to the left hand hole in the same

block. This cuts out the galvanometer in the set and cuts in the external galvanometer.

**The Slide Wire Bridge.** A simple form of Wheatstone bridge is in Fig. 65.

A piece of resistance wire about No. 24 B. & S. is stretched between two binding posts *D E*. Their distance apart is a little over one metre.

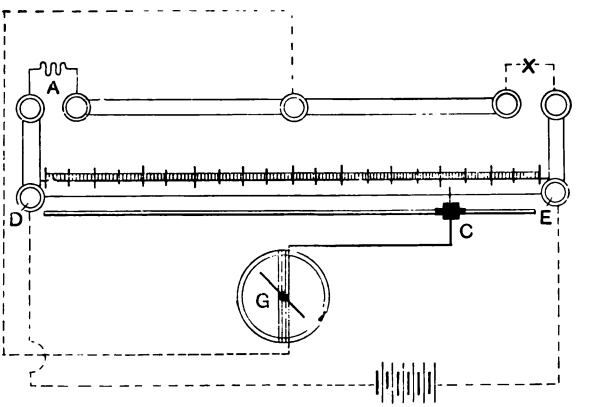



FIG. 65.

Under this wire lies a scale graduated into 1000 equal divisions with a zero at each end.

Brass or copper strips of too small a resistance to be considered lie on the base connecting the binding posts as shown.

The resistance to be measured is connected at $x$.

An adjustable resistance is connected at $A$,

partly taking the place of the rheostat in the P.O. and other Bridges.

A battery and galvanometer being connected as shown, the slider $C$ is moved along the wire $D\,E$ until the galvanometer needle stands at zero.

When the balance is obtained, the resistance of $x$ will equal the result obtained by multiplying $A$ by the length of wire between $C\,E$ and dividing it by the length between $D\,E$.

The length of the wire can be read either in millimetres or divisions of one thousand.

**Formula.** Let $x$ be the unknown resistance, $R$ the resistance at $A$, $A$ the length between $D\,C$ and $B$ the length between $C\,E$. Then $R = \frac{R \times B}{A}$.

**The Stearns Bridge.** An ingenious application of the Wheatstone bridge to the measurement of the resistance of bare wire in continuous lengths is found in the Stearns bridge.

One each of the $x$ terminals of a bridge is connected to a contact device consisting of a metal roller and a form of knife edge.

The bare wire is wound from one drum on to a second drum passing in its passage through both of the contact devices.

The bridge is adjusted to zero by making the rheostat equal the resistance of a length of wire between the contacts.

The drums being then started, each successive

length passes the contacts and a continuous measurement takes place.

The distance between these contacts being unchangeable, the resistance of the wire included between them should also remain unchanged.

**The Sage Ohmmeter.** The Sage ohmmeter, Fig. 66, is a portable slide wire Wheatstone Bridge of

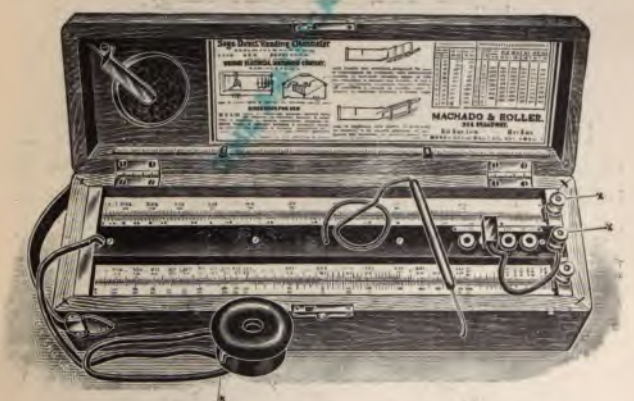



FIG. 66.

peculiar pattern with a telephone receiver as well as a galvanometer.

The adjustable rheostat takes the form of a fine wire, under which are marked resistances in various colors.

A stylus $S$ is connected to the telephone $T$ as shown in Figs. 67 and 68 and can be touched at

any point on the wire rheostat. Plug *P* cuts in various resistance coils in the Bridge arm, the plug holes being colored to correspond with the markings on the scale.

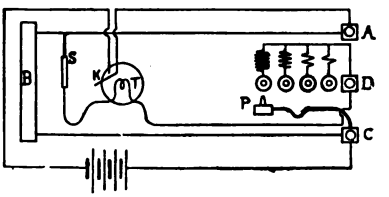



FIG. 67.

In operation the resistance to be measured is connected to posts *A* and *D*. The telephone is held to the ear and the battery key on the telephone is closed. The stylus is tapped at various points on the rheostat wire until no sound is heard

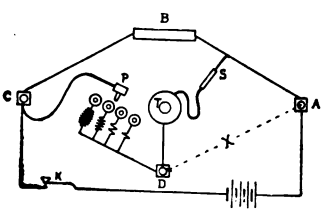



FIG. 68.

in the telephone, the resistance being measured will be found in the figures at the point of stylus contact, where no sound was obtained.

The numbers are to be read in that color corre-

sponding to the plug socket in use. If the plug is in a red hole, read the red figures, and so on. The plug must always be in one of the sockets when testing.

FIG. 69.

**The Evershed Testing Set.** This simple testing outfit, Fig. 69, consists of an ohmmeter and a hand

915402

generator. To test an insulation or other resistance, all that is required is to connect the resistance to the binding posts, turn the generator handle and read the resistance off the dial. No calculations whatever are necessary.

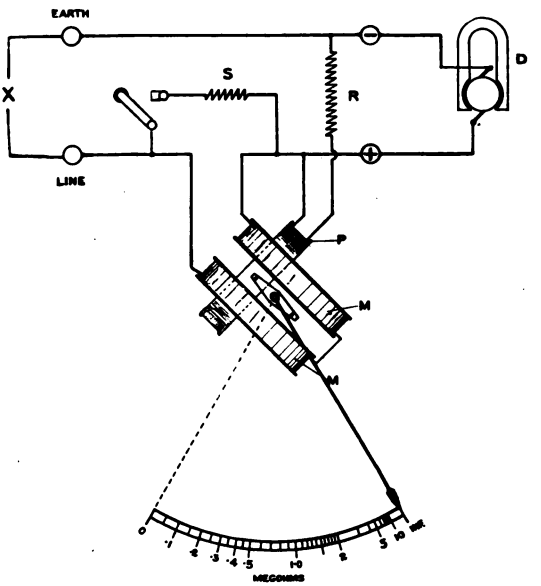



FIG. 70.

The connections of the Evershed set are given in Fig. 70.

Current from the generator $D$ flows to the ohmmeter $- +$ where it divides. Part travels through the pressure coil $P$ and resistance $R$ and tends to

turn the magnetic needle towards the infinity mark on the scale. The other path of the current is through the current coil $C$ and the fault $x$.

If $x$ has no appreciable resistance the current in $C$ will be dependent only on the resistance of $C$ and the e.m.f. of the generator.

In this case the current coil will deflect the needle to zero, which is where the influence of each coil is equal.

The resistance of $x$ is in series with the current coil. It is obvious therefore that the more resistance in $x$ the less current in $C$. And coil $P$ turns the needle in proportion as its influence becomes strengthened by reason of the weakening of $C$.

Increase of voltage from the generator does not affect the result as it affects both coils.

The scale is graduated in ohms, the instrument being constructed with various sensibilities.

The different instruments range from 2500 ohms to 5 megohms in one instrument and 25,000 ohms to 50 megohms in another. Sets for intermediate readings can also be had.

The generators furnished range from 100 volts to 1000 volts in output.

# CHAPTER VII.

## TESTING WITH GALVANOMETER.

**Current flow and e.m.f. in a Circuit.** The current flow in all parts of a circuit is equal, but the e.m.f. varies according to where it is measured.

In Fig. 71 a fine German silver wire is stretched between terminals $A\ E$ and connected in series with a battery and an ammeter $G$; $F$ is a second ammeter connected in the circuit or $G$ may be shifted.

When the battery current flows through $A\ E$, the ammeter placed at $G$ or $F$ shows the same reading, the current at $G$, $F$, or in fact in any part of the circuit is the same.

Connect a voltmeter $V$ at $A$ and $E$ and note reading, then connect $V$ between $A\ B$, $B.C$, $C\ D$ and $D\ E$ and the latter four readings added together will equal the one between $A$ and $E$.

If the wire $A\ E$ is of uniform resistance, the e.m.f. between points at equal distances along it will also be equal.

If $V$ be connected as at first to $A$ and the connection at $E$ be drawn along the wire towards $A$, the e.m.f. will be observed to decrease. This il-

lustrates what is termed "the fall of potential," or if electrical work is being performed, the fall of e.m.f.

If the voltmeter be connected across any two points and a greater current flow be permitted by means of an adjustable resistance *R*, the e.m.f. will rise with the current.

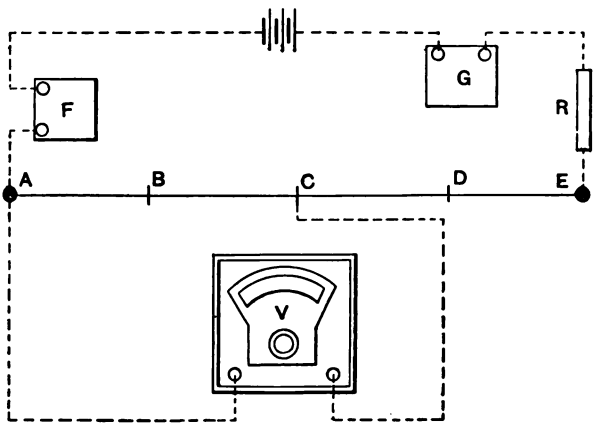



FIG. 71.

As long as the resistance of *A E* remains unchanged, a greater current flow requires a greater e.m.f.

**Applications of Ohms Law.** If the resistance between the connections of *V* be known, the cur-

rent flowing may be computed from the deflection of $V$ by Ohms law. $I = \frac{E}{R}$ or the current equals the e.m.f. divided by the resistance.

For example, let $A\ E$ measure 2 ohms and $V$ indicate 4 volts, then the current will be $\frac{4}{2}$ or 2 amperes.

If any two readings be known, the third can be computed by Ohms law.

From the e.m.f. and current flow find the resistance. $R = \frac{E}{I}$ or the resistance equals the e.m.f. divided by the current. In this example $\frac{4}{2} = 2$ ohms.

And from the current and the resistance find the e.m.f. $E = R \times I$ or the e.m.f. equals the resistance times the current in this example $2 \times 2 = 4$ volts.

The applications of Ohms law and the fall of potential will be found in the potentiometer, the shunt ammeter and in various tests to be described later.

**Testing Resistance.** Let an unknown resistance be placed in series with a battery of constant e.m.f. and a galvanometer. Note the deflection and replace the unknown resistance by an adjustable resistance. Adjust the latter until the second deflection is equal to the first and the two resistances are equal.

If the adjustable resistance be of known value this method can be pursued, but a more practical method is to first ascertain the constant of the galvanometer.

**The "Direct Deflection" Method.** This is the simplest method of testing resistances or insulations and is capable of extended application.

It is based upon the fact that the greater the current flow through the galvanometer the wider the angle of deflection.

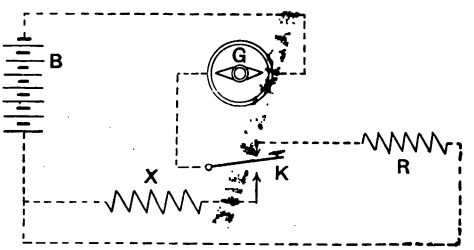



FIG. 72.

A known resistance $R$, Fig. 72, is put in circuit with the galvanometer $G$, battery $B$ and double contact key $K$.

After noting the deflection, the key is depressed and the unknown resistance $x$ thrown in circuit. The second deflection is then noted and compared with the first.

If the galvanometer deflections are proportional to the current, $x$ will be as many times the resist-

ance of $R$ as the deflection through $R$ is greater than that through $x$.

For example, let $R$ equal one hundred ohms and the deflection through it be ten degrees. The second deflection through $x$ is twenty degrees. This shows that the current flowing through $x$ is twice that which flowed through $R$ and therefore the resistance of $x$ is only one-half that of $R$, or fifty ohms.

**Formula.** As a formula, let $x$ equal the unknown resistance, $R$ the known resistance, $D$ the deflection through $R$ and $d$ the deflection through $x$. Then $x = \frac{D \times R}{d.}$

In case the galvanometer resistance is to be allowed for it is to be added to $R$ but deducted from $x$. Calling it $r$, the formula stands $x = \frac{D \times (R + r)}{d} - r$

**Galvanometer Figure of Merit or Constant.** It is customary in many uses of the galvanometer to determine the figure of merit or constant of the galvanometer.

This is the resistance through which the galvanometer will give a deflection of one scale degree for one volt of e.m.f.

If 100,000 ohms could be inserted in series with the galvanometer and one volt e.m.f. and still one degree of deflection be obtained, the figure of

merit or constant of the galvanometer would be 100,000 ohms.

And if 50,000 ohms with one and one-half volts gave a deflection of three degrees, the constant would be as lollows:

The e.m.f. is one-half as much again as required, therefore the deflection will be one-half as much again or one-third more than it should be. Reducing it by one-third gives two degrees of deflection.

And it is evident that if two degrees are obtained through a certain resistance, one degree would be obtained through twice the resistance.

One degree of deflection only requires one-half the current to produce it that two degrees does, therefore the constant for the galvanometer is $50{,}000 \times 2$ or 100,000 ohms.

**Formula.** To make a formula out of this let $D$ be the deflection through the resistance, $R$ be the resistance, $V$ the e.m.f., and $x$ the constant required. Then $\frac{D \times R}{V} = x$ or $\frac{3 \times 50{,}000}{1\frac{1}{2}} = 100{,}000$.

The terms constant, figure of merit and sensibility are used to mean the same. Sensibility or constant are the most generally adopted, however.

**With Shunts.** If a shunt is used in obtaining the constant the deflection and resistance must be multiplied by the value of the shunt which will be known as $n$, as before.

In the above example let the shunt be $\frac{1}{10}$ with a multiplying power of 10.

The formula will be then

$\frac{D \times R \times n}{V} = x$ and the last example $\frac{3 \times 50000 \times 10}{1\frac{1}{2}}$ or 1,000,000 ohms.

Using the $\frac{1}{10}$ shunt only one-tenth of the current went through the galvanometer but as it is for example assumed to give the same deflection as at first, its constant is ten times higher.

In some cases the full battery perhaps 100 cells is used to get a constant by shunting the galvanometer.

The constant is then not for one cell but for the whole battery.

Its value will be the product of the deflection, the known resistance and the shunt.

**Formula.** Using the above letters, (battery of one hundred cells),

$$D \times R \times n = \text{constant.}$$

EXAMPLE. Let the deflection be 16°, resistance 100,000 and shunt $\frac{1}{100}$. Then constant for the battery in use will be $16 \times 100{,}000 \times 100$ or 160 megohms.

And it is evident that the constant for one cell will be one-hundredth of the above, or 1,600,000 ohms.

Where the figures of resistance become high it is preferable in calculating to substitute the value in megohms or fractions of a megohm.

Second Example. Let the figures used in determining the constant be, $R = .1$ (one-tenth) of a megohm, $D$ be 100° and the shunt $\frac{1}{1000}$.

In testing an unknown resistance with the same shunt and battery the deflection is 10°.

Then the constant is $100 \times .1 \times 1000$ or 10,000 megohms.

And the unknown resistance $\frac{10,000}{10}$ or 1000 megohms.

**Summary of Rule.** When using the same shunt battery and galvanometer the value of an unknown resistance will be determined by dividing the constant by the deflection obtained through this unknown resistance. If a different shunt $s$ is used the formula will be

$$\frac{D \times R \times n}{d \times s}$$

**Deflection Constant.** It is often convenient to use the deflection obtained through a known resistance as the constant. The degrees of deflection obtained in a test will then be calculated in terms of the resistance used when getting the constant.

For example, let the deflection through one megohm be 85 degrees. Then the resistance-con-

stant would be one degree through 85 megohms, and the deflection-constant would be 85 degrees through one megohm.

In testing an unknown resistance under the same conditions of battery, shunt, etc., the deflection is 170 degrees. Then $\frac{85}{170} = \frac{1}{2}$ and the unknown resistance is one-half megohm.

Rule: Divide the deflection-constant by the deflection through the unknown resistance; answer is in terms of standard used to determine constant.

**Formula.** Let $R$ be the standard resistance, $D$ the deflection through it, $x$ be the unknown resistance, $d$ the deflection through $x$. Then

$$x = \frac{D \times R}{d}$$

If $R$ be one megohm the calculation is simplified for quick working, and becomes $\frac{D}{d}$ in megohms.

**Direct Deflection with Queen Set.** The Queen Acme set, $T$ 460, may be used for tests of this nature; a special set is, however, constructed having a resistance in series with the galvanometer. The latter can also be shunted by manipulating the Bridge.

The $T$ 460 set is used as follows:

To obtain the constant, connect a resistance of about 100,000 ohms such as one of the glass slabs,

between the top left hand post and the + battery post.

Remove all plugs from the commutator between the Bridge arms and plug in all coils. Connect in one cell of battery by means of the flexible cords.

The setting should be as in Fig. 73. It will be seen from this diagram that the circuit starting downwards from the slab runs through the + battery post, battery cell, battery key *B a*, rheostat

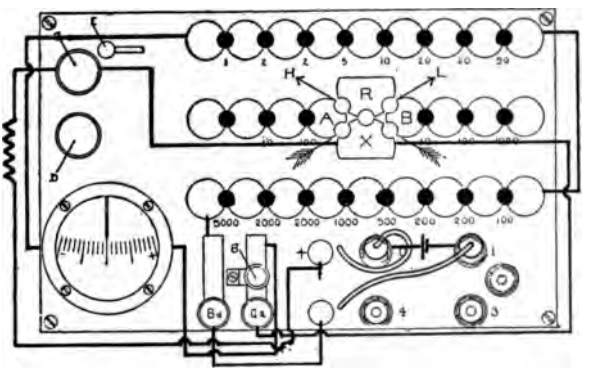



FIG. 73.

blocks, galvanometer, galvanometer key *G a*, to the main post and to the upper part of resistance slab.

The slab, galvanometer and battery will thus be in series when *B a* and *G a* are depressed.

If any plugs have been left out in the rheostat, the resistance of the coils they control will also be included in the circuit.

When *B a* and *G a* are depressed a deflection of the galvanometer will ensue. If this deflection is one degree, the constant is 100,000 ohms.

If more than 1 degree, remove plugs from rheostat and add resistance thereby interpolated to resistance of slab. The constant will be the figure so obtained.

And if less than one degree, a lower resistance than 100,000 ohms must be used, but it is not likely that this will be the case.

The constant having been obtained, detach slab and connect resistance or insulation to be measured in its place.

If the deflection is too small add more cells. A larger battery can be added by connecting it to the battery posts, detaching the flexible cords and cups from the battery in the case.

To determine the resistance now being measured, divide the constant by the deflections obtained and multiply the result by the number of cells used.

For example, let the deflection be 10° with 5 cells. $\frac{100{,}000 \times 5}{10} = 50{,}000$ ohms.

The deflection has been increased 10 times, which would show that the resistance was only one-tenth of the constant or 10,000 ohms.

But as five times the e.m.f. has been used, the result must be multiplied by five.

Another method is to use the deflection obtained through 100,000 ohms as the constant. Divide this constant by the deflection obtained in the test and

multiply by the number of cells used. The answer will be in terms of 100,000 ohms.

For example, let 8° be the deflection constant through 100,000 ohms with one cell, and 4° be that through the unknown resistance with five cells. Then $\frac{8}{4} \times 5 \times 100{,}000 =$ the unknown resistance, or 1,000,000 ohms.

In such tests the resistance of the galvanometer may be neglected.

If it is desired to use only the galvanometer of the Acme set, remove the plugs from the commutator, insert all other plugs and connect to the main posts at left end of case. The galvanometer and key are now directly connected to these binding posts.

**Measuring Resistance with Voltmeter.** The voltmeter being considered merely as a galvanometer, it may be substituted for the latter.

The deflection obtained from a battery or other source of current is noted.

This deflection is actually through the resistance of the voltmeter.

A second deflection is then taken with the unknown resistance in series with the voltmeter and battery.

This deflection is dependent upon the current allowed to flow through both the voltmeter resistance and the unknown resistance.

The first deflection multiplied by the voltmeter

resistance will give the resistance through which one degree of deflection could be obtained, or the constant.

The value of the second deflection can then be calculated from this constant, the latter divided by the second deflection will give the total resistance. Subtract the voltmeter resistance and the result will be the value of the unknown resistance.

The connections are as in Fig. 74, more extended

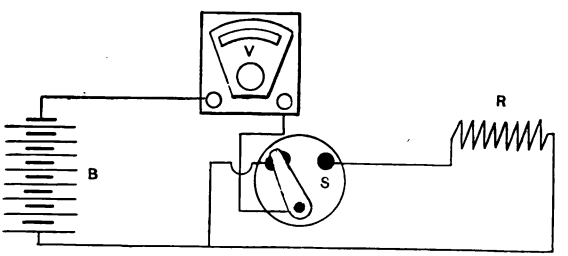



FIG. 74.

description of this test being given in the chapter treating on measurements with the voltmeter.

**Testing Resistance of Galvanometer.** In many tests it is necessary to know the resistance of the galvanometer being used. If it is not marked on the instrument it may be found by the following method:

Arrange the galvanometer *G*, Fig. 75, in series with an adjustable resistance *R* and battery *C*.

The resistance and battery should be so selected that the deflection of $G$ is about one-half the scale. This is to enable readings to be made with accuracy.

Having noted first deflection, increase resistance $R$ until deflection of $G$ is just one-half of its first deflection.

The battery used must be constant or its variations will affect result. They may, however, be compensated for. Battery resistance is omitted.

The resistance of the galvanometer will equal the resistance of $R$ as measured at the time of one-half deflection less twice the original resistance of $R$.

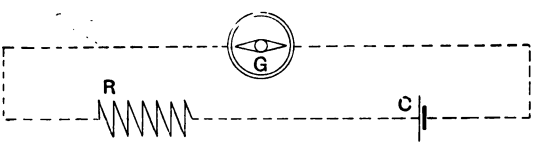



FIG. 75.

For example, let $R$ equal 10,000 ohms and the first deflection be 40°, increase $R$ until at one-half deflection it equals say 25,000 ohms. Then 10,000 $\times 2$ or 20,000 from 25,000 leaves 5000 ohms, the resistance of the galvanometer coils.

**Formula.** As a formula, let $R$ be first resistance, $r$ be second resistance; then $G = r - 2R$.

**Resistance of Galvanometer by Bridge.** Connect the galvanometer $G$ between the posts used in ordinary resistance tests, as in Fig. 76.

Adjust the rheostat $R$ until the needle of $G$ is at the same deflection when key is open or closed. Then the resistance of $G$ will equal resistance in $R$ multiplied by result obtained from dividing resistance in arm $B$ by that in arm $A$.

**Battery Tests.** Tests of battery cells may be to determine e.m.f., internal resistance or life. For the latter no directions will be given.

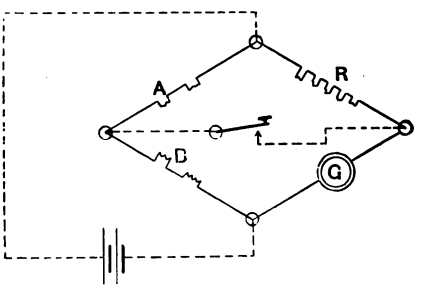



FIG. 76.

The simplest test for e.m.f. is to connect a voltmeter across the terminals of the cell. A high resistance voltmeter must be used, one with not less than 80 ohms per volt is desirable.

The cell being disconnected from any other circuit will give its e.m.f. on open circuit.

Tests of similar nature may be made by discharging cell through resistances of different values.

Tests for internal resistance are needful in many electrical operations and a number of methods will be described.

**First Method of Measuring Resistance of a Cell.** Take open circuit e.m.f. of cell with voltmeter of known resistance $R$.

Add resistance $r$ in series with cell and voltmeter and adjust until e.m.f. deflection is one-half.

Calculation: Add additional resistance to that of voltmeter so as to obtain total resistance in series with cell. Subtract twice the resistance of voltmeter and answer will be that of cell. This test is only suitable where internal resistance of cell is high.

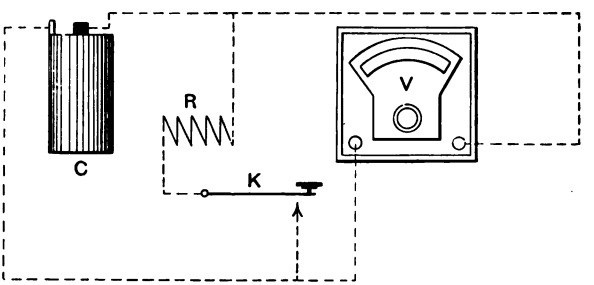



FIG. 77.

EXAMPLE. Voltmeter = 521 ohms, e.m.f. 1.5 volts; adding 530 ohms reduces e.m.f. to .75 volt. Total resistance $521 + 530 = 1051$. This less $521 \times 2$ or $1042 = 9$ ohms.

**Formula.** $(R+r) - 2R$ = cell resistance.

**Second Method.** In Fig. 77 $C$ is the cell whose internal resistance it is desired to measure, $V$ a

voltmeter, $R$ a known resistance and $K$ a key to connect $R$ across the circuit when desired.

First read the e.m.f. of $C$ with the key open; then depress key and read the e.m.f. across $R$.

Then the resistance of the cell will equal the first e.m.f. minus the second e.m.f. divided by the second e.m.f., or as a formula, $r = R \times \frac{v - v_1}{v_1}$.

The second e.m.f. is really the drop across the resistance.

EXAMPLE.—Let first e.m.f. be 2 volts, resistance be 2 ohms, second e.m.f. across resistance be 1.5 volts, then internal resistance is

$$2 \times \frac{2 - 1.5}{1.5} \text{ or } 2 \times \frac{.5}{1.5} \text{ or } 2 \times \frac{1}{3} = \frac{2}{3} \text{ ohm.}$$

**Third Method.** Another shunt method is by using a resistance which equals the total resistances in the circuit such as galvanometer, wires, etc. Connect this in shunt across the cell, also connect galvanometer and wires to which shunt was adjusted across cell.

The connection would be similar to the last figure, only the shunt should be directly connected across $C$.

Having made these connections, note deflection, and then remove shunt by opening key.

Note second deflection. Add resistance in galvanometer (or voltmeter) circuit until second deflection equals first.

The value of the added resistance will be the internal resistance of the cell.

At the first deflection, there was a two branch divided circuit of equal resistances, the current then through galvanometer was one-half the total flowing.

At the second reading the added resistance cut down the current by one-half, but by a series resistance instead of a shunt.

**Fourth Method.** The simplest test of internal resistance is with the voltmeter and ammeter. Connect ammeter so as to obtain reading of current using a resistance to control current.

Take e.m.f. reading directly across cell terminals.

Then by ohms law $R = \frac{E}{I}$.

In making this last test the current from the cell may be reduced which is an advantage by adding a resistance in series with it. The ammeter is to be included in the circuit.

The e.m.f. $V$ of the cell on open circuit is first read. With the resistance in, the e.m.f. is again read $v_1$. The current ($I$) is also read on the ammeter.

Then $r$ or the resistance of the battery is equal to $\frac{V - v_1}{I}$.

Most of the above methods are only suitable for non-polarizing cells or cells of low internal resist-

ance. The Wheatstone Bridge methods are preferable.

**Resistance of Battery by Bridge.** In Fig. 78 *C* is the cell to be measured connected to line posts of bridge.

A key *K* and the galvanometer *G* is connected as shown.

Make the reading of *G* equal whether *K* is open or closed by adjusting rheostat *R*.

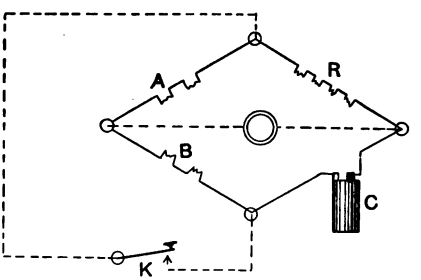



FIG. 78.

**Formula.** Then the resistance of *C* will equal the result obtained by multiplying *R* by $\frac{B}{A}$.

In the formula *R* is resistance of rheostat, *B* that of arm *B* of bridge, and *A* that of arm *A* of bridge.

**Measuring Current Flow of Cell.** The rate of current flow of a cell may be deduced from Ohms

law after reading the e.m.f. and the internal resistance.

But it may also be measured with an ammeter on short circuit.

The latter method is not always desirable. The test can also be made with a tangent galvanometer.

The tangent galvanometer can be used as an ammeter providing the directive force of the earth's magnetism be known for the place where the measurement is made.

This directive force is used in the form of a constant. It varies however, from time to time.

The constant of the place of measurement is multiplied by the radius of the galvanometer coil in inches and the result divided by the number of turns in the galvanometer coil. This gives a constant for the galvanometer.

When a current produces a deflection of the needle, the tangent of the angle of deflection multiplied by this galvanometer constant equals the current flow in amperes.

EXAMPLE.—A cell of battery applied to the terminals of a 10 turn coil which had a radius of 6 inches produced a deflection of 18°. The test was made in New York.

Constant of the galvanometer equals $\frac{.744 \times 6}{10}$ or .4464.

Tan (tangent) 18° = .3249.

Then $.4464 \times .3249 = 1.4518$ amperes.

**Formula.** Let $I$ = current flow; $H$ constant of location; $r$ radius of coil; $N$ number of turns of coil; $G$ constant of galvanometer; $T$ tangent of deflection. Then $G = \frac{H \times r}{N}$ and $I = G \times T$, or

$$I = \frac{H \times r}{N} T.$$

# CHAPTER VIII.

## THE POTENTIOMETER.

**The Potentiometer.** Referring back to Fig. 71 let the negative terminals of two independent battery cells be attached to *A* and their positive terminals to *E*. No current will flow along *A E* if the e.m.fs. of the cells are equal. This can be proven by inserting a voltmeter in series with either cell or between *A E*. One e.m.f. is opposing the other e.m.f. If now two cells in series be applied to *A E* and a third cell be connected in multiple between *A E* as before, a voltmeter or galvanometer will show current due to the excess of e.m.f. from two cells against one. Or if all the cells are equal, the deflecting force will be equal to that of one cell.

Connect a voltmeter or galvanometer in series with the one cell and leaving the negative terminal connected to *A* move a wire from the voltmeter along *W*. A point will be reached where the voltmeter or galvanometer will settle to zero showing the e.m.f. of the one cell is equal to that opposing it from the two cells. As the wire W is of uniform resistance, the e.m.f. across one-half of

it will be one-half that across its entire length. The point of zero will then in the present case be in the middle at $C$, and the relation between the two lengths of wire will equal that between the two e.m.fs. Or the length $A\ C$ will be to $A\ E$ as the e.m.f. of the one cell will be to that of the two cells.

Although there is some similarity between a potentiometer and a Wheatstone bridge there exist two great differences. The bridge has one source

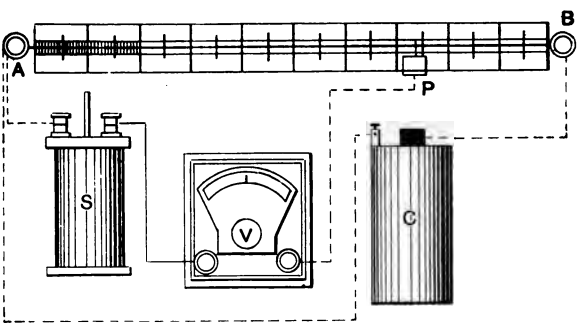



FIG. 79.

of e.m.f. and two circuits; the potentiometer two opposing e.m.fs. in one circuit.

A balance is obtained in the bridge when the points of equal e.m.f. in two circuits are connected through the galvanometer.

In the potentiometer the point of equal e.m.f. between two e.m.fs. is found in one circuit.

A simple form of potentiometer is shown in Fig. 79. Between the binding posts $A\ B$ is

stretched a fine resistance wire. A sliding contact $P$ moving on a guide rod carries an index which indicates on a scale graduated into 1000 equal divisions. This scale may conveniently be one metre long and the wire No. 24 B. & S. gauge. A standard cell $S$ is connected, one terminal to $A$ and the other terminal to the voltmeter $V$. The second terminal of the voltmeter goes to the sliding contact $P$. If $V$ is not provided with a key one may be inserted between $A$ and $P$. The cell the e.m.f. of which is to be compared is connected to $A$ and $B$. Similar terminals of each cell must be connected to $A$.

Contact $P$ being moved, $S$ and $C$ being both in circuit, a point on the wire will be found where $V$ gives a zero reading.

When the balance is obtained, the scale divisions from $A$ to $P$ will bear the same relation to those from $A$ to $B$ that the e.m.f. of cell $S$ does to the e.m.f. of $C$. The e.m.f. of $S$ being known the e.m.f. of $C$ is easily calculated.

Let $S$ be 1.019 volts, $A\ P$ be 755 and $A\ B$ 1000. Then 755:1000 : : 1.019 is to $C$ or $\frac{1000 \times 1.019}{755} =$ 1.349 . . . . volts.

If $A\ P$ were 10 and $A\ B$ 1000, $C$ would equal 101.9 volts. It is evident that $S$ should be less than $C$ or no point of zero will be found.

As this is a zero method, that is the object being to reduce $V$ to zero, $V$ need not be calibrated in volts but may be any form of galvanometer. If

it were desired to check a voltmeter, the latter would be inserted across $A$ $B$, the reading on this voltmeter should equal the e.m.f. obtained by the calculation.

As the sliding of the contact $P$ only cuts in or out a resistance formed by the wire, the resistance of the latter may be determined. Each scale division will then have a value in ohms or fractions of an ohm.

To make this clear, let the wire be for example 10 ohms, then each of the 1000 divisions on the scale will equal $\frac{1}{100}$ of an ohm.

And in the foregoing example 755 divisions would equal 7.55 ohms.

The whole example would read 7.55 ohms : 10 ohms : : 1.019 is to 1.349 volts. the same result as before.

To check an ammeter it would be placed in series with a steady source of current. A shunt or known resistance is also in *series* with the ammeter.

Leads of no appreciable resistance are run from each end of the shunt to $A$ and $B$, The e.m.f. across this shunt is first determined. The current flowing is then calculated by dividing the e.m.f. across the shunt by the resistance of the shunt, or $I = \frac{E}{R}$. This should equal the reading on the ammeter. The shunt must be of sufficiently high resistance to give a drop of e.m.f. greater than

the e.m.f. of $S$. For example, let the shunt be 5 ohms, and the e.m.f. across it be 10 volts. Then $\frac{10}{5} = 2$ amperes. Some of the foregoing rules may be modified in actual work with the more complicated forms of potentiometers, but the principles remain the same.

If it is desired to measure a high e.m.f. and yet not apply it in full to the potentiometer, any desired e.m.f. may be taken off by means of resistances. A number of resistance coils being placed in series with the high e,m.f., connection may be made between two or more for the desired e.m.f. In the case of an e.m.f. of 100 volts, let 10 volts be needed for purposes of measurement. Place in series two coils one of 100 ohms and one of 900 ohms. Connecting across the 100 ohm coil will give an e.m.f. of 10 volts, across the 900 ohm coil, 90 volts, and across the two coils, 100 volts. The reason for using such high resistances is to keep down the current. The actual resistances used may vary according to circumstances, their relation to one another is only of importance.

In some tests it is desirable to connect the known source of e.m.f. across $A\ B$ and the unknown across $A\ P$.

By using a charged storage battery and suitable high resistance a steady e.m.f. may be obtained for some hours. Dry cells are not suitable as their curve of e.m.f. drops too abruptly.

In using the potentiometer with a large battery

of constant e.m.f. the latter is connected to $A\ B$, its positive pole to $A$.

A standard cell $S$ is connected, positive pole to $A$ and negative pole through voltmeter or galvanometer to $P$.

$P$ is moved until there is no deflection. The divisions between $A$ and $P$ are noted, or if the scale is graduated in terms of resistance of $W$, the ohms are noted. Call this $R$.

The standard cell being replaced by the cell under test, a point of balance is again sought. Call the resistance of divisons from $A$ to $P$ in this case $r$. Then the e.m.f. of the cell being tested is to the e.m.f. of $S$ as $r$ is to $R$.

It may be necessary in order to obtain greater accuracy to use two or more standard cells in series between $A$ and $P$.

For example, let e.m.f. of the standard cells $S$ be 2.038 $A\ B$ equal 1000 and $A\ P$ equal 100. Then the e.m.f. across $A\ B$ will be $\frac{1000}{100} \times 2.038$ or 20.38.

Substituting the cell $C$ to be tested for $S$ it is evident that zero balance will be again obtained when its e.m.f. balances the e.m.f. between $A\ P$. It may be then read in terms of the e.m.f. across $A\ B$ or in terms of $S$.

Suppose balance now is obtained at 125. This will be $\frac{125}{1000}$ of $A\ B$ or 2.547 likewise $\frac{125}{100}$ of $S$.

In figures $\frac{125}{1000} \times 20.38 = \frac{125}{100} \times 2.038$.

The modern testing sets are generally suitable for use as potentiometers as the following examples will show.

As plug switches are used instead of sliding contacts, the relations corresponding to divisions on a scale will be those of resistances in ohms. In the testing sets, the resistance equivalent to that between $A\ P$, Fig. 79, is made 100 ohms and is not changed. The resistance equal to $P\ B$ is adjustable and is first made high.

As the sliding of $P$ merely changes the *relation* between $A\ P$ and $A\ B$ the same result is obtained by changing only $P\ B$. This which is not feasible in the slide wire instrument becomes an advantage in the plug switch pattern.

In the following two tests consider the $B$ arm to represent the wire $A\ P$ and the rheostat the wire $P\ B$. The $B$ arm plus the rheostat will then equal the total resistance of wire $W$ or from $A$ to $B$.

Although the examples given are measurements of e.m.f. or current, the potentiometer is equally well adapted for comparing resistances and insulations.

**Checking Voltmeters.** Voltmeters may be checked by comparison with a standard instrument or by the potentiometer method.

In the former case, the standard instrument and the one being checked are connected in multiple across the e.m.f. at the same point and their readings compared.

**Potentiometer Method with Queen Set.** Unplug 10,000 ohms from rheostat, unplug *A* arm of Bridge and unplug 100 ohms only from *B* arm. Remove plugs from commutator except one in upper right hand hole, that is, connecting *R* and *B* blocks.

Disconnect flexible battery cords from battery tips. Connect negative terminal of a standard cell or cell of known e.m.f. to line post *C* and its positive terminal to + battery post.

Connect line e.m.f. to battery posts, + to + and – to – .

Depress *B a* and *G a* keys and change resistance in rheostat until no deflection occurs. If needle goes towards + on scale, reduce rheostat and vice versa. Proceed carefully as the balance will occur at a point of slight change in the rheostat.

When balance is obtained, add 100 ohms to the reading of the rheostat and divide by 100 or point off two places.

Multiply this result by e.m.f. of standard cell and answer is e.m.f. of outside circuit.

For example, suppose balance was obtained with 8855 ohms in rheostat and e.m.f. of standard cell is 1.44.

Then $\frac{8855+100}{100} = 89.55$ and this multiplied by 1.44 = 128.95 volts as e.m.f. of outside circuit.

**Formula.** Let *R* = rheostat at balance; *B* =

resistance of $B$ arm, $e$ = e.m.f. of standard cell, and $E$, e.m.f. to be found.

Then $\frac{R+B}{B} e = E$, or what is the same thing, $\frac{R+B}{B} \times e = E$.

**Potentiometer Method with Willyoung Set.** The connections for the measurement of an e.m.f. by the potentiometer method are shown in Fig. 80.

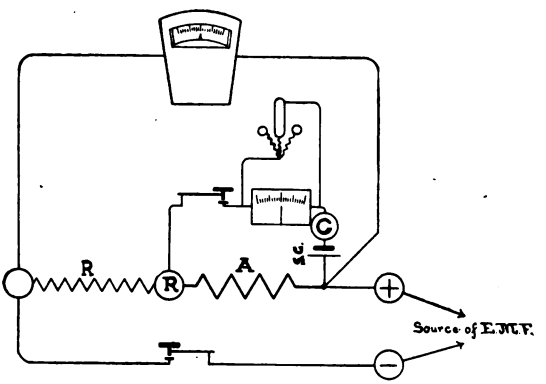
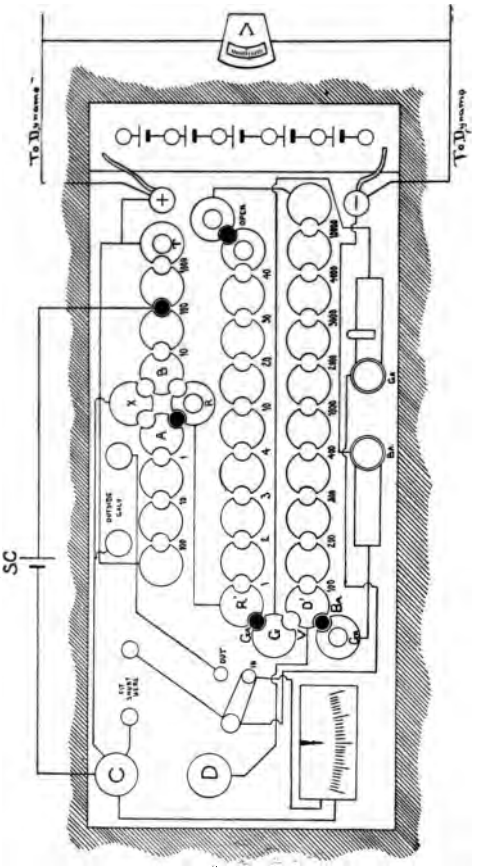



FIG. 80.

The operation to be performed here is the checking of a voltmeter.

$S\,C$ is a standard cell, $A$ one arm of the bridge, $R$ the rheostat.

A key and shunt are in the galvanometer circuit and a key or switch in the power circuit. The latter may be a tap from a direct current main or




Layout of Fig. 80.

storage battery. But a few lamps or other resistance should be put in circuit to avoid danger of excessive current.

The standard cell negative terminal is connected to $C$ and the positive terminal to a movable plug which for the present is placed in the 100 ohm hole of the $A$ arm.

The outside e.m.f. is connected, positive terminal to + battery post and negative terminal to – battery post. $R$ is then adjusted until needle remains at zero, always closing the battery key first.

$R$ should be first made very large and gradually reduced. Unplug say 20,000 ohms and then replace plugs one by one.

On a circuit of 110 volts $R$ will be somewhere near 9000 ohms.

It will be found that at a certain point a very slight change in the rheostat will reverse the galvanometer deflection.

To determine the e.m.f. of the line, which should be also the reading on the voltmeter if it is accurate, figure as follows:

Add 100 (the resistance in the $B$ arm) to the resistance needed in the rheostat for a balance and point off two places, that is, divide the above sum by 100. Multiply the result by the e.m.f. of the standard cell and the result is the e.m.f. of the line.

For example, suppose 7816 is the rheostat reading, 1.44 the e.m.f. of cell. Then $\frac{7816+100}{100} =$

79.16 and $\times$ 1.44 = 113.99 volts. The difference between this result and indication on voltmeter is the error of the latter.

Of course if the standard cell is one volt, the e.m.f. would be 79.16 or the rheostat reading plus the $B$ arm and divided by one hundred.

**Formula.** Let $E$ represent e.m.f. of line (or indication voltmeter should show), $e$ the e.m.f. of standard cell, $R$ resistance in rheostat, $B$ resistance in $B$ arm.

Then $$E = \frac{R+B}{B} \times e.$$

# CHAPTER IX.

## CONDENSERS.

**Charge and Discharge of Condenser.** Connect a condenser $C$, battery $B$, galvanometer $G$ and key $K$ as in Fig. 81.

Depress $K$ and a deflection will be noted at $G$. This is due to the charge of the condenser.

Release $K$ and upon the back contacts meeting,

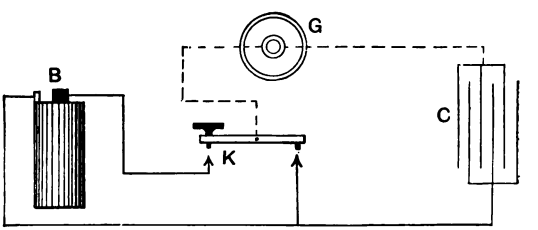



FIG. 81.

a second deflection takes place at $G$ but in the opposite direction.

Again depress $K$ so as to open the back contact but not close the battery circuit. Upon again releasing $K$ a deflection will ensue but very much less than the previous ones. And this last operation being repeated, decreasing deflections will be noted.

If $K$ be depressed for varying intervals of time and released the deflections will also vary.

It takes a certain length of time to charge a condenser. Increasing the battery will reduce the time of charge.

If a Kempe discharge key is used the connections will be practically the same. The back contact of the key in the figure will be the top contact in

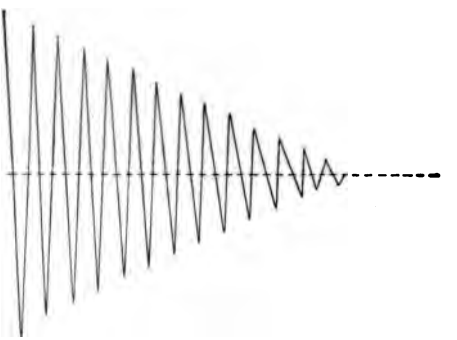


FIG. 82.

the Kempe key, and the front contact the lower contact of the Kempe key.

The capacity of the condenser is measured by the extent of the deflection upon first short circuiting it through the galvanometer. This is true when battery power and other conditions are equal.

If the discharge of $C$ be observed with an appropriate apparatus, it will be seen to be oscillatory as in Fig. 82, not steady as that of a battery cell.

A condenser does not store up electricity, the operation called charging merely leaves it under an electric strain which is relieved when it is discharged.

It may be likened to a spiral spring which is suspended from one end and has a weight at the other end. If this spring be pulled still farther down, an ability to do work or a potential is given it. Now upon releasing the spring, it contracts, pulls up the weight, and then slightly expands again, causing the weight to jump up and down until the force is exhausted.

The spring and weight have an oscillating motion even as does the condenser discharge show an oscillatory character.

A condenser offers the resistance of its insulation to a direct current, in other words will not allow a current of this character to pass through it.

But the effect of an alternating current is not arrested by a condenser. An ordinary vibrating bell will not be rung by a battery through a condenser except one tap due to charge. The alternating current of a telephone magneto will ring the bell with which it is equipped without trouble through a condenser.

This does not show, however, that the alternating current actually passed through the dielectric. It is the inductive effect between the plates, a condenser acts therefore by the induction taking place between its parts.

To avoid complications of words the condenser

is said to retain a charge and to permit itself to be discharged.

**Measurement of Capacity.** The capacity of a condenser is measured by comparing the discharge deflections with those obtained from the discharge of a condenser of known capacity. The latter is termed a standard condenser.

The operation is as follows:

Charge standard ($S$) for a certain length of time, say one minute, then discharge it and note deflection ($D$).

Then replace standard by the condenser under test ($C$). Charge and discharge under precisely similar conditions and note deflection ($d$).

The connections may be similar to Fig. 81 or the battery may be connected directly to the condenser through the key. The galvanometer would not be then in circuit during charge. Or the galvanometer may be shunted or short circuited.

The condenser under test will bear the same relation in capacity to the standard that the deflections do to those obtained by discharging the latter.

**Formula.** Or as a formula,

$$S : C :: D : d. \quad \text{Then } C = S\frac{d}{D}.$$

Another method by the bridge is as follows: A standard condenser and the condenser to be tested are connected in a similar manner to the

two arms of the bridge. Each condenser takes the place of the coils in one arm.

An adjustable resistance is connected in the binding posts provided for the $x$ or unknown resistance.

A discharge key and battery are connected taking the place of the regular battery in the bridge. The condensers are charged and discharged, and the resistances adjusted in the other sides of the bridge until no deflection obtains.

At balance the two condensers are to each other in respect to capacities inversely as the two resistances are to each other.

EXAMPLE. Capacity of standard condenser $S$ is .3 (three-tenths) microfarad. Resistance $R$ on same side of the bridge is 1800 ohms. Resistance $r$ on side of bridge where condenser $T$ to be tested is connected, is 1200 ohms. Then $T$:.3 : : 1800. 1200 or $\frac{.3 \times 1800}{1200} = .45$ microfarad.

**Formula.** Using above letters, $T : S :: R : r$.

**Insulation of Condenser.** A condenser can be tested for insulation by charging it through a shunted galvanometer. When fully charged the deflection should return to zero.

If a deflection is shown after charging is completed it indicates that current is passing through condenser. The value of this current and the resistance of the fault in the condenser are computed

from the galvanometer constant as in any direct deflection method.

But this method does not give as close a test of very high insulations as the loss of charge method.

**Insulation by Loss of Charge.** A condenser retains its charge (or electric strain) for a length of time dependent upon the perfection of its insulation. This property gives a method for determining its insulation as well as by the usual resistance tests.

A condenser is attached to a battery for a given length of time and then discharged through a galvanometer. The deflection having been noted, the condenser is again charged under precisely similar conditions and left with its terminals insulated for a given period of time and again discharged through the galvanometer.

The two deflections being compared the loss of deflection in the second reading is a measure of the loss of charge. This loss being due to the state of insulation, the latter is therefore determined.

In a good standard condenser this loss for a short period of time is inconsiderable.

As cables and wires act in a similar manner to condensers, their insulation can also often be determined by the loss of charge method.

The following figures are approximate as the actual substance or fluid varies somewhat. For purposes of comparison, however, the figures are sufficiently accurate.

## TABLE IV.

Specific inductive capacity taking air as 1.

| | |
|---|---|
| Flint Glass | 10 |
| Plate Glass | 7.06 |
| Gutta-percha | 2.62 |
| Mica | 5 |
| Paraffin wax | 2.31 |
| Pitch | 1.80 |
| Shellac | 2.59 |
| Sulphur | 3.82 |
| Olive oil | 3.16 |
| Castor oil | 4.78 |
| Turpentine | 2.23 |

# CHAPTER X.

## CABLE TESTING.

**Cable Testing.** If a resistance be shunted across a condenser it will be found that no steady deflection can be obtained until the condenser is charged.

The effect of shunting the resistance around the condenser has had the practical result of adding capacity to the resistance.

A few experiments with a key, battery and galvanometer will show what the effect would be of adding capacity to a signalling circuit.

As the insulation in a cable acts as a condenser dielectric, the choice of an insulation of little capacity is necessary (see Table IV.)

One of the tests of a cable is to determine its capacity, the other two main tests are as to its insulation and the conductivity of the conductor or core. The insulation of a cable may be that between its core and the earth. Or in the case of a multiple cable having several separate cores, the insulation between these cores.

Where cables are armored with iron or steel wire, or lead covered, the armor or lead covering forms one of the two connections in insulation or capacity tests.

As in most cases, the cable armor or lead sheath is in direct contact with the earth, a connection may be had with the latter. But a good contact on the armor or sheath is preferable.

In testing multiple cables, all the cores not being tested at the time should be grounded. This is done by twisting a bare copper wire around a bared end of each conductor and then to the armor or sheath.

If no very delicate instruments are at hand, all the cores may be so connected or "bunched" omitting the armor connection. An insulation test made between the bunch and the ground will give the multiple insulation of all the cores. This must be less than that of one core as the copper surface to the insulation is so much increased. If a large deflection results, the cores may be thrown off one at a time, watching the deflection. Should it suddenly decrease upon detaching a core from the bunch, trouble is evident in that core.

In preparing core ends for attachment to the testing circuit, much care must be exercised. The insulation should be removed in a tapering form as one would point a lead pencil.

Absolutely no dampness must exist on the insulation or current will be conducted from the copper to the sheath and destroy the value of the test. A good plan is to coat the cable from the copper under the binding posts with hot paraffin.

In testing cables one point will be noticed, the deflections on an insulation test will gradually de-

crease. This is due to electrification of the cable. The insulation apparently improves.

The deflections are generally read after one minute's electrification.

In a multiple cable the actual resistance of each conductor must be worked out and then all the resistances added together. Dividing this by the number of conductors will give the average insulation of the cable.

In speaking of insulation, the cable length must be specified. For instance, if a piece measuring 1000 feet had an insulation of 1000 megohms, a piece only half as long would be 2000 megohms. Its insulation surface and therefore its leakage surface is only one-half.

It is customary to reduce the result to the average per mile. In the foregoing example, the insulation would be 189 megohms per mile.

The rule is to multiply the insulation obtained by the length of the cable reduced to miles or parts of a mile.

In the direct deflection method of testing cable to be described, the same reading should be given whichever terminal of the battery is grounded. The negative terminal of the battery to the cable conductor shows up a fault in a cable quicker than the positive pole for reasons to be given later.

The temperature at which a test of insulation is made is of prime importance. The insulating properties of gutta-percha, rubber and compounds of similar nature decrease very rapidly with in-

crease of temperature. Taking the case of gutta-percha at 50 degrees Fahrenheit as of unit resistance, at 60 degrees it would be less than one-half, at 75 degrees only one-fifth, and at 90 degrees only one-twelfth. With other insulations the decrease of resistance may be even greater than this. It is customary to test cables at 75 degrees Fahrenheit or to correct the readings to that temperature.

Tables of corrections will be found in most large works on testing, such as Kempe's "Hand Book of Electrical Testing," or Hoskaier's "Electrical Testing of Telegraph Cables."

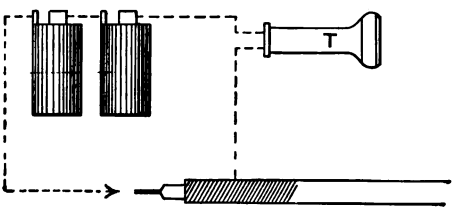



FIG. 83.

**Telephone Test of Insulation.** A simple test of cable insulation may be made with a telephone receiver and battery as in Fig. 83.

One wire makes good connection with the cable armor or lead covering the other wire being touched to the cable core.

Upon making the first contact with the core a click will be heard in the telephone owing to the charge of the cable.

But if the connection be kept closed for a minute or so the cable will be charged.

Subsequent tapping will give no click if the insulation be good. The clicks are of course due to current leaking through the insulation.

**Cable Testing for Insulation Resistance.** In Fig. 84 *B* is a battery, *R* a reversing key, *G* a galvanometer, *S* a shunt box, *C* the cable, *E* an earth con-

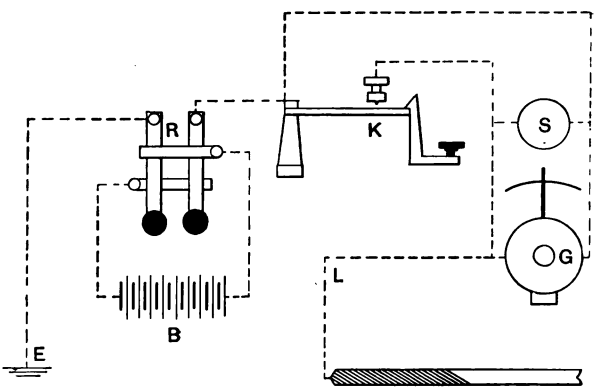



FIG. 84.

nection, *L* a lead from the cable core to the galvanometer connection. *K* is a short circuit key, that is, one which can be left closed to short circuit and cut out the galvanometer and also be opened to cut in the galvanometer.

Before connecting *L* to the cable, test the insulation of *L*. Connect one end as in the figure to

the contact of $K$, depress one button of $R$ and open $K$, using a shunt according to the sensibility of $G$ and strength of $B$.

No deflection should appear.

If any deflection deduct it later from readings in testing cable.

Close short circuit key $K$; connect other end of $L$ to cable and open $K$. Any deflection of $G$ will be due to earth currents.

If the deflections so obtained are in the directions of deflection when battery is used, deduct same from cable readings, if in the reverse direction, add them.

Shunt $G$ with say $\frac{1}{100}$ shunt, closing $K$ and press one button of $R$. As long as $K$ is closed the current all goes into the cable in a similar manner to charging a condenser. After ten seconds, open $K$, keeping $R$ still down and a deflection of $G$ will ensue.

If off the scale use a higher shunt or reduce battery and repeat charge of cable.

If too small, use lower shunts or increase battery.

Repeat the latter test several times, allowing cable to charge for one minute, noting readings. Then repeat as many more times, but depress other button of $R$, reversing battery and deflection.

The values of these readings may be worked out from the galvanometer constant and an average taken to represent the insulation of the cable.

The foregoing cannot necessarily cover every minor point, but the main operations are given.

To sum up: First, obtain the constant of the galvanometer; this operation was described elsewhere. Second, test insulation of the leads. Third, test for earth currents. Fourth, charge cable. Fifth, cut in galvanometer and shunt. Sixth, reverse battery and repeat fifth. Seventh, strike average of readings.

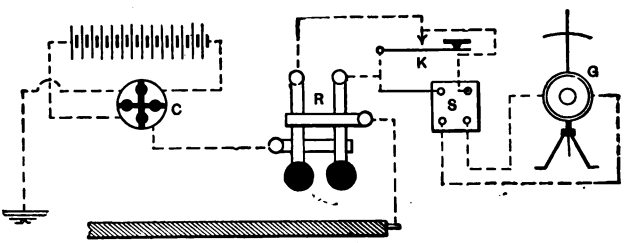



FIG. 85.

Principle allowances to be made are for: shunt, battery, insulation of leads and earth currents.

A slightly different connection for the above test is shown in Fig. 85.

The cable is connected to the reversing key *R*, and a commutator *C* permits of reversing the battery connections, putting either terminal to ground. Or the battery can be cut out entirely and the cable tested for earth currents by directly grounding the connection between *R* and *C*

**Testing Ground Connection.** Connect positive terminal of battery to ground and negative terminal through shunted galvanometer to ground.

Shunt should be so adjusted that deflection is not off the scale. If necessary put resistance in series with galvanometer. Next short circuit ground connection by connecting positive wire to ground wire on galvanometer.

The deflections in each case will show the state of ground connection. The better it is the less difference there will be between the two deflections.

**Cable Insulation with the Willyoung Set K.** The general scheme of this test is in Fig. 87.

The cable is normally grounded by its sheathing or armor and one terminal of the battery is grounded.

The constant of the galvanometer is first calculated by setting the Bridge as in Fig. 86. One cell of battery is used and the shunt arm is on $\frac{1}{100}$.

Adjust the rheostat until a deflection of say 10 degrees is obtained.

Multiply the resistance unplugged by the deflections and the multiplying power of the shunt.

In this example let the rheostat be 1800, then $1800 \times 10 \times 100 = 1{,}800{,}000$ ohms. This is the resistance through which the galvanometer is deflected one degree by one cell of battery.

The cable is now connected in as in Fig. 87, to *D*, and a ground connection made from *G r* at the lower left hand side of the case.

Close the battery key for 10 seconds and then close the galvanometer key, the deflections being noted.

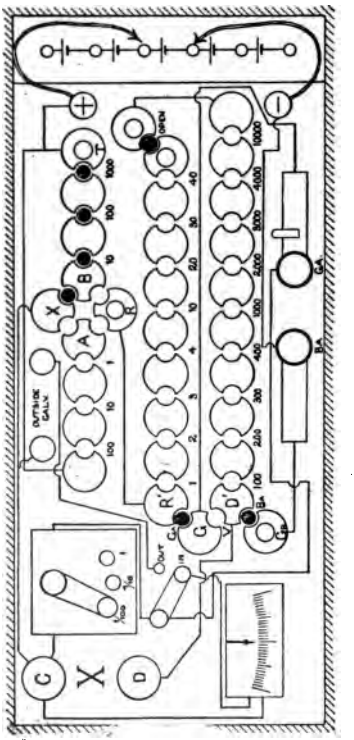



FIG. 86.

The battery has been increased to six cells, therefore the constant is to be multiplied by 6 and divided by the deflection obtained.

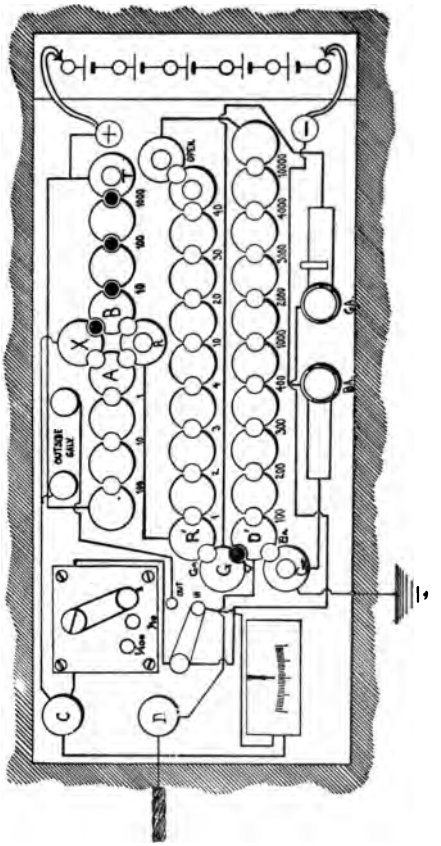


FIG. 87.

Owing to condenser action of the cable there will be a rush of current into the cable at first. It will be well to shunt the galvanometer by the $\frac{1}{100}$ shunt until the charge of the cable is completed.

By using larger battery increased resistances may be measured.

**Cable Testing by Loss of Charge.** In testing the insulation of cable by the loss of charge method, the cable is charged and discharged, its capacity being compared with that of a standard condenser.

The cable is then charged for one minute and disconnected with its terminal free in the air. This is done by using a key similar to the Kempe discharge key before described.

At the end of one minute, the cable is discharged and the reading noted. Comparison of several such readings show the ability of a cable to retain a charge, *i.e.*, its insulation.

**Formula.** Let $D$ be the deflection upon instantly discharging the cable, $d$ that after one minute. Then the percentage of loss of charge will be

$$\frac{D-d}{D} \times 100$$

In many cases where delicate apparatus is not at hand the loss of charge method can be used for approximate results.

The writer has tested multiple conductor submarine mine cables in New York Harbor with a few cells of dry battery and the galvanometer in a portable testing set.

When the direct deflection method failed owing to want of sensibility in the galvanometer, the difference of deflection made after charge, insulate and discharge gave results.

**Capacity Tests.** The capacity test of a cable is similar to that described in testing condensers.

A standard condenser is charged and discharged and the galvanometer deflections noted. The cable is then substituted for the standard condenser and the deflections noted. Comparison of the two results gives a comparison of the capacity of each.

The calculations are made as in condenser tests.

**Conductivity Tests.** The conductivity of a cable conductor may be measured with a Wheatstone Bridge as in any similar test for conductivity or resistance.

When both ends are available they are connected to the bridge in the usual manner.

If only one end is at hand it is often possible to use a second conductor of the same cable, looping the two together at the distant end. The resistance of one will be then one-half the reading if both are similar in diameter, material and length.

If a ground connection becomes necessary it

must be made with the greatest care that it interposes no undue resistance.

**Locating Faults in Cable.** If the grounded fault were of practically zero resistance and the ground connection between the fault and the battery also of zero resistance, the location of a fault would be easy.

It would then only be necessary to measure the resistance of the cable core up to the fault from both ends of the cable. As the core is of uniform resistance, the two results would be in the same ratio as the lengths of the cable.

For example, let the total length of the cable be 10,000 feet and its total resistance 21 ohms. Measuring from one end $A$ the resistance to the fault is 14 ohms. From the other end $B$, the resistance is 7 ohms. Then as 14 is $\frac{2}{3}$ of 21, the fault would be $\frac{2}{3}$ of the total length of the cable from $A$. Or 6666 feet from $A$ and 3333 feet from $B$, neglecting fractions.

But ground connections or faults rarely fulfil the above condition, in fact they usually vary from time to time. It becomes necessary to use a test such as the Varley or Murray, which disregard the resistance of the fault.

A method of locating a fault as in Fig. 88 may be adopted in certain cases.

A good cable and the faulty one are looped at

the distant end $D$. The resistance of the loop $A\ B$ is then measured by the Bridge method. One $x$ terminal of a Bridge being grounded, the other terminal is applied to $A$ and the resistance $A\ F$ is measured, and similarly the resistance $B\ F$. It is evident that both $A\ F$ and $B\ F$ include the resistance of the fault to earth.

The resistances $A\ F$ and $B\ F$ being added together, subtracting the resistance of $A\ B$ will leave twice the resistance of $F$ to earth. Twice the resistance because it has been added in both $A\ F$ and $B\ F$.

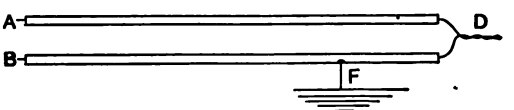



FIG. 88.

If now the resistance of $F$ be subtracted from $B\ F$ it will give the resistance of $B$ to $F$. Knowing the resistance of the cable per foot the distance can be determined.

EXAMPLE.—Let $A\ B$ measure 22 ohms; $A\ F$ equal 26 ohms, and $B\ F$ 16 ohms. Then $26+16 = 42$, and less $22 = 20$ ohms. One-half this, or 10 ohms, is the resistance of the fault to ground. The resistance of $B\ F$ or 16 ohms less $10 = 6$ ohms.

If the cable conductor resistance were 11 ohms per mile, the fault would be $\frac{6}{11}$ of a mile from $B$, or 2880 feet.

To properly understand the Varley and Murray tests consider a Wheatstone Bridge the arms of which are equal. The rheostat is replaced by a length of cable and the unknown resistance is also replaced by a length of cable, both being similar in resistance per foot.

If both lengths are the same, their resistances are the same, the Bridge balances and no deflection takes place.

Now shorten one length and add resistance *R* in series with it until the Bridge again balances,

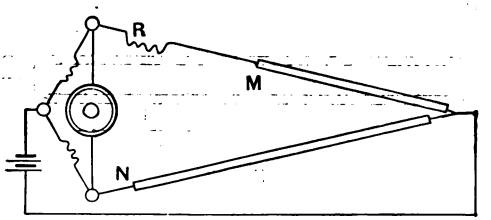



FIG. 89.

Fig. 89. The added resistance equals that of the piece cut off.

If the resistance per foot is known, the length of the shorter piece can be easily calculated.

Instead of connecting in the battery by a wire as shown, use earth connections at each point.

The only result will be to interpose a resistance in the battery circuit. It will not affect the balance but only reduce the effective power of the battery. This may be overcome by enlarging the battery.

Before making the test the copper core resistance of the loop between $M\ N$ must be known either by calculation or measurement.

The latter is known as the Varley test, a more complete description is as follows:

**The Varley Test.** In this test for a fault or earth connection the Bridge is connected as in Fig. 90. The battery is grounded and its circuit is completed by the ground at the fault $F$. The faulty

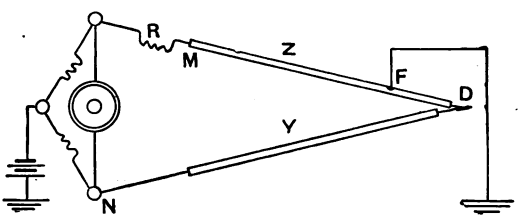



FIG. 90.

cable is looped or connected at its distant end $D$ with a good cable.

To obtain a balance it is clear that the rheostat $r$ must be adjusted until its resistance added to that of the cable core between $M$ and $F$ together equal the resistance of the core from $F$ to $N$.

It is also clear that the resistance of the ground at $F$ only reduces the energy of the battery current.

The test is therefore independent of the amount of core exposed to the ground at $F$.

**Formula.** Using the letters in Fig. 90, let $z$ be the resistance of cable from $F$ to $M$, $Y$ that of the cable from $F$ to $N$, $R$ the resistance of the entire cable loop, $F$ the resistance of the fault, $r$ the resistance of the rheostat when galvanometer is balanced.

Then $Y + z = R$, and $Y + F = r + z + F$ or $Y = r + z$.

$Z$ then equals $\frac{R-r}{2}$.

The distance $x$ of the fault from $M$ is

$$\frac{R}{z} = \frac{L}{x} \text{ or } x = \frac{z\,L}{R}$$

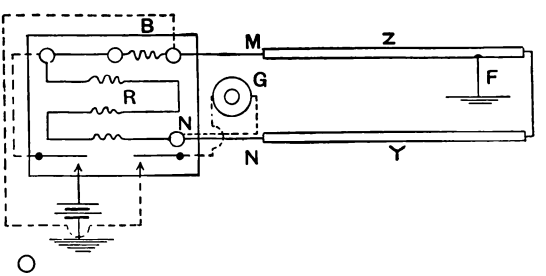



FIG. 91.

**The Murray Test.** This is somewhat similar to the Varley test but one arm of the Bridge is made adjustable. One regular Bridge arm is used, the other being replaced by the rheostat giving an arm of large adjustment.

The circuit is given in Fig. 91. $B$ is one Bridge arm, $R$ the rheostat now the second Bridge arm,

$Z$ the faulty cable between $M$ and the fault $F$, $Y$ the remainder of the faulty cable and also the good cable in the loop.

The rheostat is adjusted until there is no deflection. From a previous discussion of the Bridge this will be seen to occur when the resistance $R$ bears the same proportion to $Y$ as $B$ does to $Z$. Or $R : Y :: B : Z$.

Suppose for example only the total length of the loop from $M$ to $N$ is 400 feet. Its resistance is 40 ohms. A fault occurs at a distance from $M$ to be determined.

Arm $B$ is 100 ohms. $R$ is adjusted and on balance reads 300 ohms. $R$ is therefore three times $B$.

$Y$ must bear the same proportion to $R$ that $B$ does to $Z$; here $Y$ must be three times $Z$.

As $Y$ and $Z$ added together equal the whole resistance of the cable, $Y$ will be $\frac{3}{4}$ and $Z$ $\frac{1}{4}$ of this resistance (or length).

$Y$ therefore equals 30 ohms, and $Z$ 10 ohms.

Or if the length is required, $Y$ is $\frac{3}{4}$, that is, 300 feet, and $Z$ $\frac{1}{4}$ or 100 feet.

**Rule.** To obtain the length of $Z$ by means of a rule for calculation. The resistance $B$ is to be divided by $B$ added to $R$ and the result multiplied by the length of the cable loop or $L$.

Same example, $\frac{100}{100 + 300} \times 400$ or $\frac{1}{4} \times 400 =$ 100 feet.

**Formula.** $R : Y :: B : Z$, or $\frac{R}{Y} = \frac{B}{Z}$.

$Z + Y = L$, then $Z = L - Y$.

$x$ or distance of $F$ from $M$ =

$$\frac{B}{B + R} \times L.$$

**Murray Test with Aone Set.** The layout of the Willyoung testing set for the Murray test is in Fig. 92.

**Formula.** Let $r$ be resistance of loop, $Y$ be distance of fault from $D$, $A$ resistance unplugged in Bridge arm $A$, $R$ resistance unplugged in rheostat.

Then $\frac{R}{A + R} = \frac{Y}{r}$, $Y = \frac{R\,r}{A + R}$.

In fault testing the negative pole of the battery is preferably connected to the cable. If the positive pole be applied and there be a bared spot in the insulation, this bared spot will be acted on by the current, and apparently improved, but the chloride of copper formed is at the expense of the copper core.

**Locating Fault by Unreeling Cable.** In this method two insulated reels are used, or an insulated tank, a galvanometer, battery, etc.

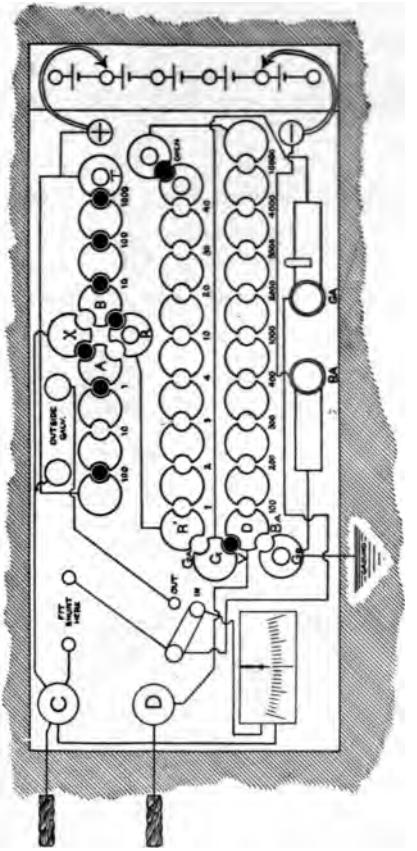



FIG. 92.

One end of the cable conductor is connected to a galvanometer the second terminal of the latter being grounded through a battery.

The cable is wound from one reel to the other, the slack passing through the water in the tank. As soon as a fault reaches the water, the galvanometer will be deflected by the current flowing through the circuit including galvanometer, battery, ground fault and cable.

If an insulated tank is used, the ground connection of battery and galvanometer is made to the water in it.

# CHAPTER XI.

## Testing With Voltmeter.

**Testing with Voltmeter.** The adaptability of a good portable voltmeter to everyday testing is surprising to those who have not studied it.

There are few tests outside of high resistance tests in cable insulation work that cannot be performed. And even the latter are possible with a sufficiently low reading voltmeter and a large battery.

A voltmeter will do everything that a galvanometer of the same sensibility will, and a great deal more.

The most useful instrument would be a double scale portable having one total scale reading one hundredth that of the other. This together with 50 cells of small but good dry battery and a few standard resistance coils would make a testing set of vast utility.

**Testing Resistance with Voltmeter.** In Fig. 93 is shown the direct deflection method of testing resistance $R$ with a voltmeter $V$. $S$ is a switch and $B$ a battery.

The e.m.f. of $B$ is first noted by moving the switch arm to the left. The arm is then moved to the right, and the e.m.f. through $R$ noted. The first deflection showed the deflection of $V$ caused by the battery $B$ through the resistance of $V$. The second deflection was through the resistances of $R$ and $V$. If $V$ was 10,000 ohms and the first deflection 10 degrees, only one degree of deflection would be obtained through ten times 10,000 or

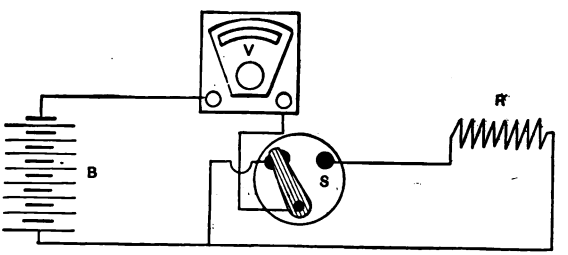



FIG. 93.

100,000 ohms, which latter is the constant for $V$. Let the second deflection be 5 degrees. The resistance of $R$ is therefore $\frac{100,000}{5}$ or 20,000 ohms, but the resistance of $V$ must be deducted. 20,000 − 10,000 = 10,000 ohms as the resistance of $R$.

The constant for the voltmeter may be calculated as above, or a formula may be used for the entire calculation.

**Formula.** In the formula let $V$ be the first deflection, $V_1$ the second deflection, and $r$ be the resistance of the voltmeter,

Then $\frac{V \times r}{V_1} - r = x$ or the resistance of $R$.

For measuring low resistances a low reading voltmeter or a millivoltmeter is preferable if a battery or low e.m.f. be used.

In many cases the current in a power circuit may be used instead of an extra battery.

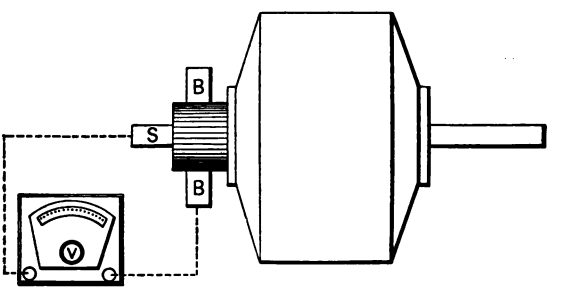



FIG. 94.

**Insulation of Generator with Voltmeter.** In testing the insulation of a generator in operation, connection is made as in Fig. 94 where $V$ is the voltmeter, $S$ the shaft or part of the framework, and $B$ $B$ the brushes.

The generator furnishes its own testing current. The e.m.f. across $B$ $B$ is first noted, then the e.mf.. from $B$ to $S$ and the last formula applied.

Care must be taken that the voltmeter is not affected by the generator and that all connections and contacts are good.

**Insulation Resistance of Armature.** A test of the insulation resistance of the entire armature may be made with the armature removed or disconnected from the fields.

A bare copper wire is wound tightly around the commutator so as to touch all segments. The testing circuit is between the shaft and this copper wire. This will give the combined leakage paths between all coils and segments to the frame.

The copper wire ensures a better contact with all segments. Where the armature coils are in series with each other and tapped to the commutator, no lower insulation will be noted than between one segment and the shaft. That is, providing all armature coil connections are good. The voltmeter should be in circuit with a tap from the mains as in the test for insulation when generator is running.

If the armature is in its place and all field and brush connections complete, the test will show the entire insulation of the machine. Brushes must in the latter case rest on the commutator.

**Testing Electric Light Wiring.** A short circuit on an electric light system generally indicates itself. On the other hand, it may be desired to test the mains for such before cutting in the dynamos.

Testing an extensive system of wiring for short circuits from a main switchboard is a difficult task without having an idea of the lamps, etc., connected to it.

If there were 1000 lamps in multiple between the leads, the resistance might be as low as one-fifth of an ohm.

Such a low resistance between two leads would be a veritable short circuit if it was due to defective insulation. If it is practicable to turn off all lamps first, the matter does not then present much difficulty.

A simple test on a circuit of say 110 volts would be to use an incandescent lamp of the same voltage.

This lamp would be connected between one side of the main being tested and a source of e.m.f., perhaps a dynamo. A wire is run from the other side of the circuit to the other terminal of the dynamo. A short circuit on the main would cause the lamp to light up. Of course the dynamo is to be disconnected from the main by its switch.

If a voltmeter be used instead of the lamp, the actual resistance is determined by simple calculation.

The e.m.f. of the dynamo is to be multiplied by the resistance of the voltmeter and the result divided by the e.m.f. observed when in series with the circuit being tested. Deducting the resistance of the voltmeter the answer is the actual resistance between the two sides of the main.

In either method, the actual location of the trouble is assisted by opening the branch circuit switches on the board one at a time. When the faulty circuit is reached upon opening its switch, the lamp goes out or the voltmeter reading decreases.

The practice of connecting pilot lamps across the circuit at motors and other apparatus is liable to cause perplexity.

A magneto bell would ring easily through one lamp. It would be troublesome to measure low resistances such as one lamp on the voltmeter, as the change of deflection would be slight. The lamp test would therefore be preferable for a short circuit.

A short circuit in a branch leading from a cut out may be hunted for after replacing one of the fuses by a lamp. The lamp will burn until the short circuit is removed. A lamp twisted loose from its base, or a faulty socket is best found by this method.

If the circuit be cut between the fault and the cut-out, the test lamp in the cut-out will cease to burn.

**Measuring Switchboard or Line Insulation.** This method has been before described in the direct deflection tests, except that here one terminal of the voltmeter is grounded.

A brief summary of the test between a switchboard bus and the ground will be given.

Take reading of total e.m.f. of circuit.

Take reading between bus and a ground connection.

Multiply resistance of voltmeter by e.m.f. of circuit, divide result by e.m.f. of bus to ground, and deduct resistance of voltmeter.

Answer will be ohms to ground of opposite bus to one used in calculation.

Should both sides of the circuit be grounded the calculations become vastly more complicated.

When testing one side, the voltmeter will be in multiple with the fault from the side to which it is connected, and vice versa.

And the two ground connections will form a connection between the mains of a resistance equal to the resistance of each ground added together.

If it were possible to disconnect one main from all connection with the other main, the test would be simple. The insulation to ground of each main would be ascertained while the other main was disconnected. But this is not often practicable.

Another method would be to disconnect both main wires from the bus-bars or from the current source, strap them together with a piece of bare copper wire, and measure the insulation to ground as if they were one wire.

This would give the joint insulation-resistance of the main to ground which after all is what is needed most in practice.

**Formula.** Let $V$ equal e.m.f. of circuit, $V_1$ e.m.f.

between main to ground, $R$ resistance of insulation to be ascertained, $r$ resistance of voltmeter.

$$\text{Then } R = \frac{V \times r}{V_1} - r.$$

In using the voltmeter for measuring resistances there is another method of working which gives the same result.

First deduct the second reading on voltmeter from the first reading. Then divide this result by the second reading and multiply by resistance of the voltmeter.

EXAMPLE. Let e.m.f. of testing circuit or that between mains be 110 volts, resistance of voltmeter 15,000 ohms, reading through resistance ground, etc., be 10 volts. Then $110 - 10 = 100$, $\frac{100}{10} \times 15{,}000 = 150{,}000$ ohms.

Working this by the first method, $\frac{110 \times 15000}{10}$ $= 165{,}000$, deduct $15{,}000 = 150{,}000$ ohms as before.

The chief advantage of the first method is that a constant can be figured for the particular instrument at a given voltage as described below.

The formula will be for the second method. Let $V$ be e.m.f. or circuit, $V_1$ e.m.f. through resistance, $r$ resistance of voltmeter then

$$\frac{V - V_1}{V_1} \times r = x$$

TABLE V.

Insulation Resistance.

| $V_1$ or Voltage through Unknown Resistance. | $V$ or Voltage of Circuit = 110 $r$ or Resistance of Voltmeter = 16,500 | $V$ or Voltage of Circuit = 110 $r$ or Resistance of Voltmeter = 17,000. |
|---|---|---|
| 1 | 1,798,500 | 1,853,000 |
| 2 | 891,000 | 918,000 |
| 3 | 588,500 | 606,333 |
| 4 | 432,750 | 450,500 |
| 5 | 346,500 | 357,000 |
| 10 | 165,000 | 170,000 |
| 20 | 74,250 | 76,500 |
| 30 | 44,000 | 45,333 |
| 40 | 28,875 | 29,750 |
| 50 | 19,800 | 20,400 |
| 100 | 1,650 | 1,700 |
| 110 | 0 | 0 |

**Resistance Table for Voltmeter Tests.** Table V. is computed for ready reference in insulation or resistance tests with a Weston voltmeter or other instrument of high resistance.

The first column gives the reading through the resistance, the second and third columns the actual resistance of the insulation.

Both the latter columns are figured for a line e.m.f. of 110 volts and for an instrument resistance of 16,500 and 17,000 ohms respectively.

Where a number of readings have to be made it is handy to figure a constant, that is, multiply the resistance of the voltmeter by the e.m.f. of the circuit.

The result or constant then can be used by simply dividing it by the e.m.f. read with insulation in series and subtracting the resistance of the voltmeter.

**Resistance of Voltmeter.** This may be determined by one of the tests given to find resistance of a galvanometer. The one-half deflection is perhaps the simplest.

Connect voltmeter to a steady e.m.f. and read deflection.

Then add resistance in series with voltmeter until deflection is reduced to one-half. The added resistance will equal resistance of voltmeter.

This is clearly so because the one-half deflection is due to one-half current, and one-half current is due to doubling the resistance of voltmeter. In order to double the voltmeter resistance a resistance has been added which is equal to it.

**Formula.** Let $V$ represent first deflection, $V_1$ the one-half deflection, $R$ resistance of voltmeter, $r$ resistance added.

Then $V_1 = \frac{V}{2}$ when $r = R$.

**Testing e.m.f. around Armature.** There are two methods of testing the distribution of e.m.f. around the armature and determining the equality of the magnetic field.

One is as shown in Fig. 95. $H$ is an insulating handle carrying two carbon brushes $A$ $B$ from which run wires $C$ $D$ for the voltmeter connection.

$A$ $B$ are set just far enough to span the insulation between two commutator segments.

By making contact on the commutator and

gradually moving $H$ in the direction of rotation, the e.m.f. is tested at different points in the armature under the influence of various parts of the field.

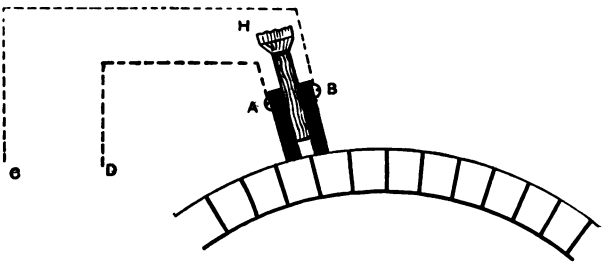



FIG. 95.

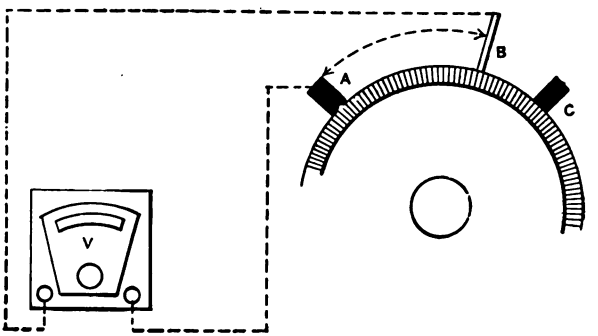



FIG. 96.

These e.m.fs. being plotted on a chart give a graphic record of the distribution of field flux.

Another method is Fig. 96, where one movable brush is used, the other voltmeter connection being on one of the regular working brushes.

This shows a gradual rise or fall of e.m.f. until the total e.m.f. of the generator is reached, but not so readily the actual e.m.f. of any one coil at a time.

**Measuring Drop across a Lamp.** To measure the drop or voltage expended in a lamp while burning the connections should be as in Fig. 97. *L* is the lamp, *V* the voltmeter and an ammeter *A* is shown

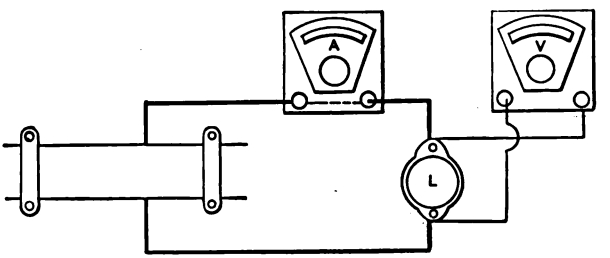



FIG. 97.

so that the current consumption can also be figured. The ammeter also is necessary if the resistance of *L* is to be determined.

The drop across *L* will be directly indicated by *V*. The current shown by *A* multiplied by the e.m.f. at *L* will give the watts expended in *L*.

**Lamp Current Efficiency Test with Voltmeter.** The amount of current taken by an incandescent

lamp on a given voltage depends upon the resistance of its filament.

Comparison of the hot resistance of one lamp with that of a standard lamp will therefore show the current efficiency of the first lamp.

If a low reading ammeter be available the current measurement may be made direct. But such an ammeter is not always at hand.

The drop across each lamp is to be measured with the voltmeter as in Fig. 97.

The e.m.f. indicated in each case will be proportional to the resistance of the lamp. And the current consumption will be in proportion to the resistance of each. The higher the e.m.f. across the lamp terminals, the higher will be its resistance and the lower its current consumption.

The e.m.f. of the testing circuit must be the same in both operations.

This test does not show the true efficiency of the lamp as no data is obtained of the relative candle powers.

And the resistance of $L$ can be computed by dividing the current reading of $A$ by the e.m.f. reading of $V$ or $R = \left(\frac{E}{1}\right)$.

Suppose $V$ reads 100 volts and $A$ .5 ampere. Then $100 \times .5 = 50$ watts, and $100 \div .5 = 200$ ohms.

**Testing a High Voltage with a Low Reading Voltmeter.** This is accomplished by the fall of poten-

tial method. Suppose it is desired to measure the e.m.f. across a circuit of about 550 volts with a voltmeter reading to 150 volts.

Connect five 110 volt lamps *L* in series across the circuit, Fig. 98.

Then measure the e.m.f. between *A B*, *B C*, *C D*, *D E* and *E F* and the sum of these e.m.fs. will equal that between *A F*.

Care must be taken that the connections of the voltmeter are made so as to include all parts of the circuit in turn. For instance, when shifting from *A B* to *B C*, the terminal from *A* must be

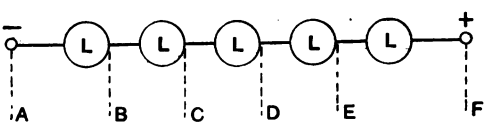



FIG. 98.

placed exactly at *B* where the other terminal of the voltmeter was. Or part of the e.m.f. in the wire or connection may be unmeasured, if this be neglected.

*The lamps must all be kept burning during this test*, or the voltmeter may be injured.

**Temperature and Resistance.** In testing coils of wire with their normal current flowing it will be found that the resistance will gradually increase, due to the current flowing in them. This increase is about .004 ohm per degree Centigrade for each

ohm of the coil (see Table VI). This is of very great importance in generator and motor tests. It would reduce the e.m.f. of a shunt generator owing to decreased field current. And it would speed up a shunt motor by reason of decreased field and decreased counter e.m.f.

TABLE VI.

Table Showing Increase in Resistance of Pure Copper Wire for Rise of Temperature above a Given Point.

| Centigrade | Increase in ohms per ohm | Centigrade | Increase in ohms per ohm |
|---|---|---|---|
| 1 | .00389 | 21 | .08169 |
| 2 | .00778 | 22 | .08558 |
| 3 | .01167 | 23 | .08947 |
| 4 | .01556 | 24 | .09338 |
| 5 | .01945 | 25 | .09725 |
| 6 | .02334 | 26 | .10102 |
| 7 | .02723 | 27 | .10503 |
| 8 | .03112 | 28 | .10894 |
| 9 | .03501 | 29 | .11281 |
| 10 | .03890 | 30 | .11680 |
| 11 | .04279 | 31 | .12059 |
| 12 | .04669 | 32 | .12450 |
| 13 | .05051 | 33 | .12837 |
| 14 | .05447 | 34 | .13226 |
| 15 | .05835 | 35 | .13615 |
| 16 | .06225 | 36 | .14061 |
| 17 | .06613 | 37 | .14593 |
| 18 | .07030 | 38 | .14782 |
| 19 | .07391 | 39 | .15171 |
| 20 | .07780 | 40 | .15575 |

This table is computed from an average between five authorities. The increase in ohms per ohm shows the fraction of an ohm which a wire one ohm in resistance would increase if its temperature were raised as per column of temperature. The coefficient .00389 is used but for ready calculation; .004 is used in the formulas, there is no absolute standard. To reduce Centigrade to Fahrenheit, multiply by 9, divide by 5, and add 32 to result.

All tests of generator and motor should record the temperature both of the air and machine.

The thermometer used for the air test should lie a few feet from the end of the shaft so as not to be influenced by air currents from a revolving armature.

And of course it should not be near any hot pipes or engine cylinders.

Temperature tests of field coils and armatures may be made with a thermometer laid on the part under test and covered with cotton waste. But such tests do not show heat inside the coils and are unreliable. A more reliable method is by taking advantage of the rise of resistance in the coil due to temperature rise.

The resistance of the coil cold may be measured and recorded. Its resistance is then measured from time to time and the temperature calculated.

For example, let the cold resistance of a shunt field coil be 120 ohms. One-half hour later it is 135 ohms.

This is a rise of 15 ohms, as it is the rise on 120 ohms, the temperature will be $\frac{15 \text{ ohms}}{120 \text{ ohms}} \div .004$ or 32° C.

A simple way to find the temperature rise is to divide the difference between the cold resistance and the hot resistance by the total resistance cold. Then find the nearest figure in the resistance column of Table VI. Against this will be the temperature. In this example

$135 - 120 = 15, \frac{15}{120} = .125$. In Table nearest is .124 or 32° C.

A third method is divide the difference between the two resistances by the cold resistance and multiply by a constant 252 for the Centigrade rise.

Same example. $.125 \times 252 = 32$.

The temperature test by resistance shows the average temperature of the coils.

For test of the temperature at specific points, a special device may be prepared.

A strip of mica about two inches square is wound with 200 turns of No. 36 silk covered copper wire. The strip is then fixed to a convenient handle if desired. This coil may be inserted in crevices between the coils of the armature, etc., its resistance being measured from time to time will give the temperature by computation as before.

**Formula.** Let $R$ be the cold resistance, $H$ be the hot resistance, $t\,C$ the temperature in Centigrade degrees, $t\,F$ the temperature in Fahrenheit degrees.

Then $t\,C = \frac{H - R}{R} \times 252$.

And $t\,F = \frac{H - R}{R} \times 423$.

**Testing for a Break in a Coil.** Testing for a break in a field coil of a dynamo or motor may be done by simply connecting a bell and battery in

series with the coil, Fig. 99, and trying if the bell rings. If it rings the circuit of course is complete.

But some field coils are of high resistance in which case a voltmeter, Fig. 100, is substituted for

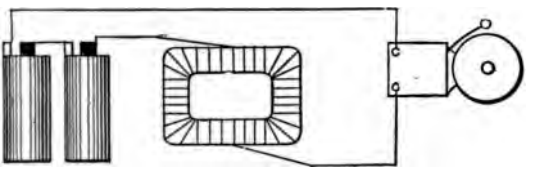


FIG. 99.

the bell. A lead may be taken from an electric light circuit to replace the battery. And if no definite readings are desired an incandescent lamp may replace the voltmeter.

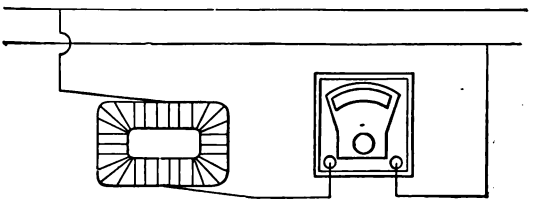


FIG 100.

But the voltmeter method will show the extent of any fault in the circuit or the resistance of the latter. The resistance is calculated from the deflections by the method given elsewhere.

**Testing the Resistance of Coils.** If a number of coils are to be compared, as in a motor or dynamo, they may be tested without disconnecting them other than from the brushes, Fig. 101.

Pass current through the coils as they are in series, using a rheostat *R* if necessary, a bank of lamps will answer.

Measure the e.m.f. across the terminals of each coil, *A B*, *C D*, *E F* and *G H*, and compare the readings; they should all be equal. If not, the

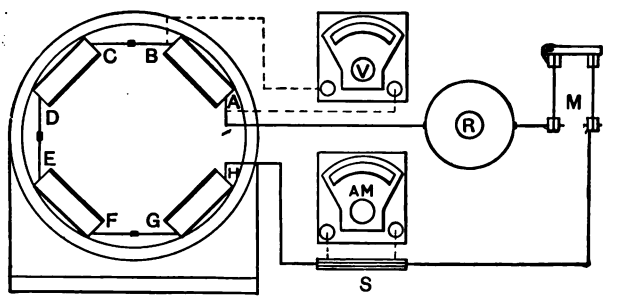



FIG. 101.

low reading coils are short circuited unless the high reading coils are faulty or open.

The actual resistance of each coil can be computed if an ammeter *A M* be put in series to give the current value.

By ohms law the resistance will equal the e.m.f. divided by the current or $R = \frac{E}{I}$. For example,

if the readings show one ampere and 15 volts, the resistance will be $\frac{15}{1}$ or 15 ohms.

**Testing Armature Coils.** Armature coils being of low resistance can best be tested by the fall of potential method.

Current from an electric light circuit is passed through a number of coils by connecting the leads to segments situated some distance apart. The exact distance will depend upon the instruments available whether low or high reading. The e.m.f. is then read between segments or from one segment to the others in succession.

A rheostat or lamp bank should be inserted in series with the current leads.

If the e.m.f. between segments is uniform the coils and connections are good.

If a jump occurs at a segment, the voltmeter needle moving a greater distance than usual, a poor connection is probably the cause.

**Testing Armature Resistance.** The connections for this test are in Fig. 102. *S* is a switch connected to a source of current. *A* an ammeter, *V* a millivoltmeter, *L* one or more incandescent lamps for resistance purposes to control testing current. Field wires of a shunt machine are disconnected. Current from *S* passes through the armature coils, ammeter, and resistance lamps.

The connections may be made with copper wire making good contact on commutator segments by inserting them under brushes *B B* of opposite polarity.

The armature is stationary during this test.

The contact must be good, a strip of copper sheet laid flat on the segments is better than a mere wire. The copper strips should be held firmly down on the segments.

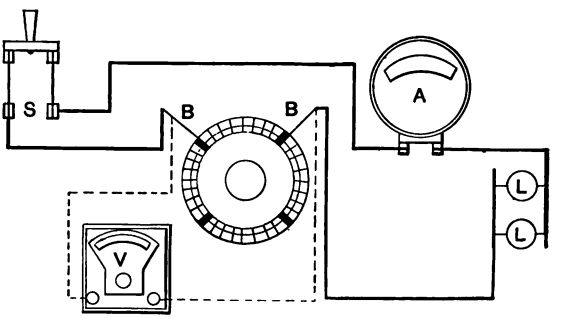



FIG. 102.

Readings are taken of the e.m.f. between the segments to which the connections of the current circuit are made.

Readings are also taken of the current indicated by the ammeter.

Then by ohms law, the resistance equals the e.m.f. divided by the current.

For example, let the current *I* be one ampere, the e.m.f. one-tenth of one volt, then one-tenth

divided by one equals one-tenth, or one-tenth of an ohm.

If the armature resistance is so low that a very small reading is given on the millivoltmeter, increase the current flow by adding more lamps in multiple.

The importance of good voltmeter contact at the commutator segments will be seen if a number of tests are made. Improve the contact in each case until no increase of deflection is noted on

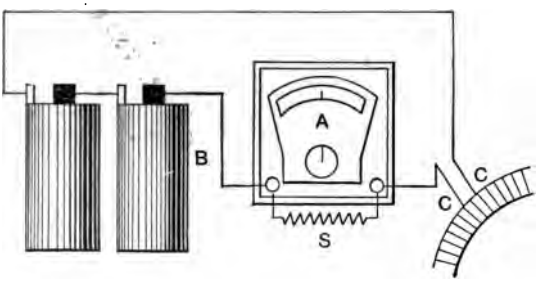



FIG. 103.

voltmeter. The larger the current through the coils the easier the test.

A form of test where an ammeter and battery are used is given in Fig. 103.

The milammeter *A* is adjusted by means of a shunt *S* to give a large deflection when the terminal leads are short circuited. Its leads are then touched on adjacent segments of the commutator.

The deflections as compared with one another give the comparisons of coil resistance.

If a coil is open or a connection broken, the ammeter will indicate low reading when spanning its segments.

If one coil is partly open, the high resistance at the fault will give a low reading on the ammeter.

If a coil is short circuited, the deflection will be greater than that across a good coil. It will be equal of course to the deflection obtained by touching the ammeter leads together.

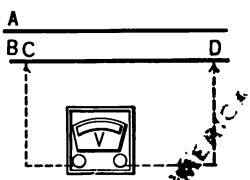



FIG. 104

**Voltmeter Test of Current in Circuit.** It is often desired to know the current flowing in a lead when it is impracticable to cut the lead and insert an ammeter.

A very close approximation may be made with a low reading voltmeter by measuring the drop along a part of the wire.

The voltmeter is connected between two bared points on the cable as in Fig. 104. The resistance of the cable between these points is read from a table of copper wire resistance. The connections must be made with care and the leads to the in-

strument be large enough to interpose no appreciable resistance.

Take the case of a cable No. 0 B. & S. The resistance per thousand feet is .096 ohm.

The low reading or millivoltmeter is connected across ten feet and a reading observed of 14.4 hundredths of a volt.

As the resistance of ten feet is .00096 ohm, by ohms law $= \frac{.144}{.00096} = 150$ amperes.

This low reading is perfectly possibly on the double scale instruments mentioned at the beginning of this chapter.

Another method would be to measure the e.m.f. across the line at two points. The first would be nearest to the generator or switchboard, the second at the point where the cable branched off to smaller wires.

The difference between the two readings would be due to the loss in the line and the loss beyond the point of second reading.

The loss in the line divided by the computed resistance of the line would give the current flowing.

The line resistance is of course its length multiplied by its resistance per thousand feet. The actual length of wire is to be used, that is twice the distance between the two points.

EXAMPLE. Cable 250 feet between points, in all 500 feet No. 0 B. & S. Resistance .048 ohm. E.m.f. at first point 115 volts at second point 110 volts; loss in line thus 5 volts.

$\frac{E}{R} = \frac{5}{.048}$ or neglecting fraction $\frac{5}{.05} = 100$ amperes.

The readings must be made as near simultaneously as possible, two adjusted voltmeters will be preferable although not absolutely necessary.

**Corrections in Resistance by " Drop " Methods.** If great accuracy is desired the drop through the voltmeter may be allowed for. The current in the voltmeter will be found by dividing the e.m.f. indicated by the voltmeter resistance. This current is to be deducted from the ammeter readings.

In armatures where the coils are in series but tapped off at commutator segments, the path through the armature coils will be double between brushes. One path is through coils on top section and another path through bottom section coils.

If a coil were open in its windings, current would still flow to the testing instruments by the second path. But a jump of the needle would be shown on the voltmeter when spanning the break.

If a connection between coil and segment were broken, the ammeter would not show any less current except at the instant when the faulty segment was under the brush or connection.

**Plotting Curves.** A graphical method of recording tests is by plotting curves on sectional paper.

In Fig. 105 are shown the readings of e.m.f.

taken half way around the commutator of a bipolar generator.

The figures at the left hand side of the chart are the voltage readings. The figures along the bottom of the chart represent the segment number.

The readings along the horizontal lines are the abscissæ, those up the perpendicular lines, the ordinates.

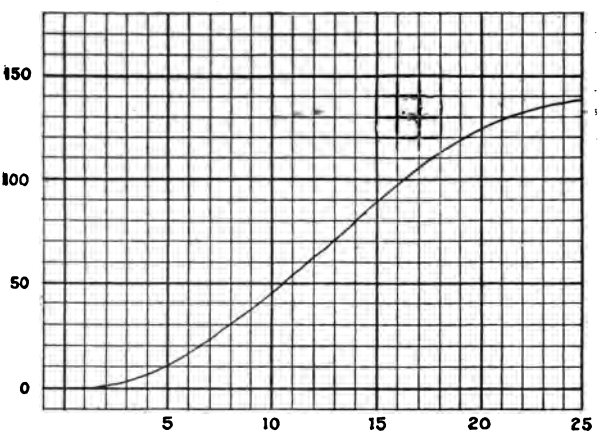



FIG. 105.

In making such a chart, the figures representing the voltage and segment numbers are first marked.

Then as a reading is taken a dot is made at the intersection of the lines representing the e.m.f. and the segment. When the total number of readings is made, the dots are connected by a line running through them.

For example, the first reading between brush and segment 4 is 5 volts, a dot is made on the vertical line corresponding to No. 4 segment, and at the point where a horizontal line from 5 volts would cut it.

A second reading of 10 volts on segment 5 is similarly marked, and another 15 volts at segment 6, and so on.

If the divisions represented by the abscissæ and ordinates are not close enough, computation may be made with a pair of dividers. But cross section paper for such charts is made with 8 and 10 divisions per inch.

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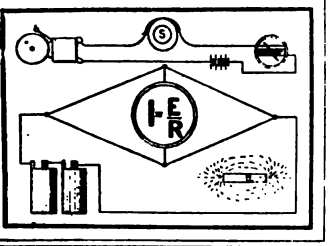


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burn, become hard, oxidize and instead of taking solder and giving it off again, will melt the solder and allow it to drop off before it can be applied to the spot desired.

Place a zinc can over the form and hold together firmly with the left hand.

Dip the brush, or stick, into the muriatic acid

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Fig. 11

and run it down the length of the seam to be soldered. It will immediately bubble and seem to smoke.

Take the hot soldering copper from the fire, dip it about an inch quickly into the sal ammoniac solution, touch the point to the stick of solder, pick off a drop of solder and apply it to the seam (Fig. 11), starting at one end and running the full length of the joint.

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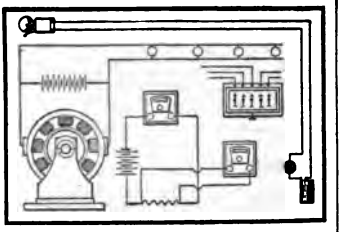



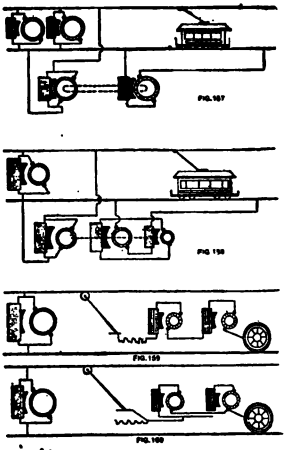

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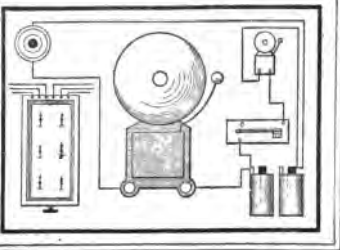



multiple (Fig. 27) as if they were in series; all would have to be closed to complete the circuit

If two bells are to be operated from one push

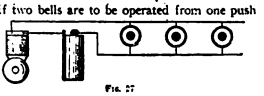

Fig. 27

they may be in series (Fig. 28), but in this case one of them must be arranged for single stroke.

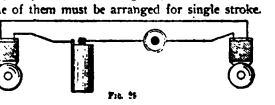

Fig. 28

If both were vibrating bells the armature of one would not vibrate in unison with the other arma-

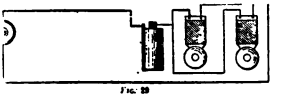

Fig. 29

ture and the result would be irregular contact breaking and intermittent ringing.

A preferable connection for two or more bells

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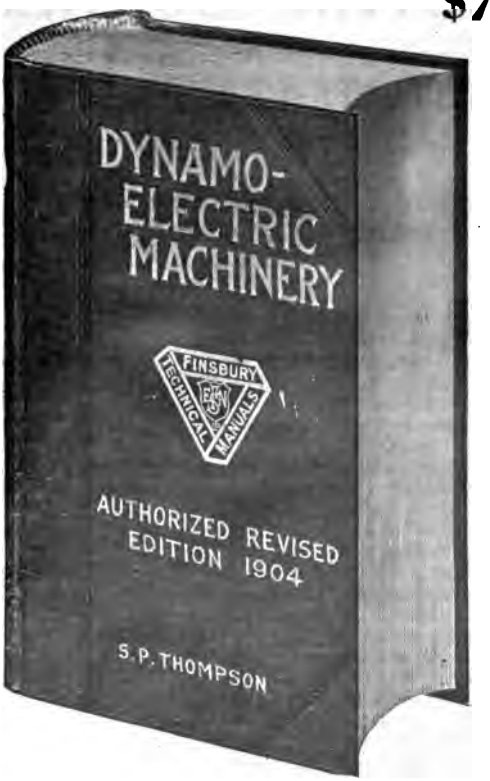


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